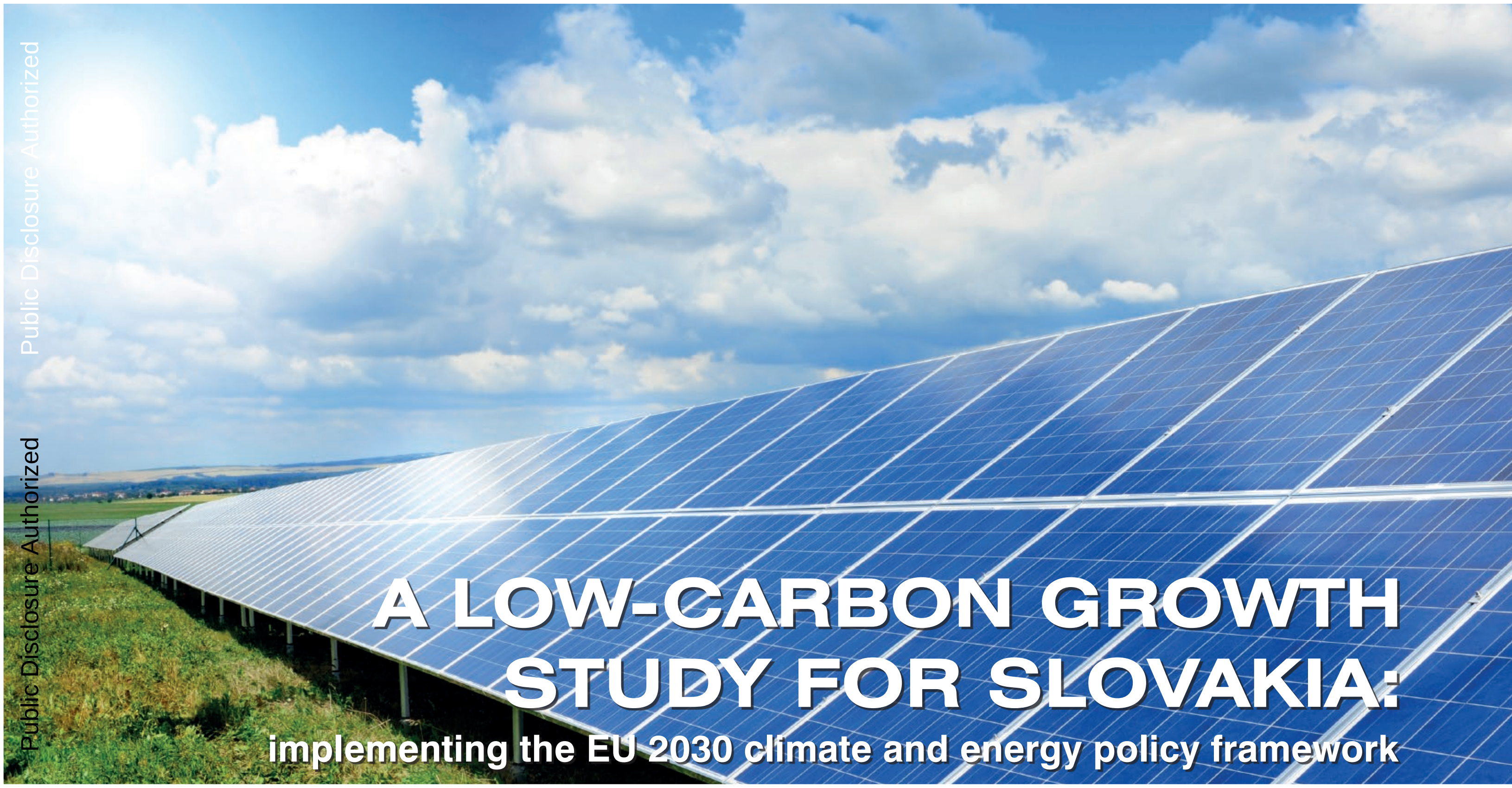

A LOW-CARBON GROWTH STUDY FOR SLOVAKIA:

implementing the EU 2030 climate and energy policy framework

The World Bank
Macroeconomics, Trade
and Investment Global Practice

Europe and Central Asia Region

JANUARY 2019

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ACRONYMS AND ABBREVIATIONS

CCGT	Combined Cycle Gas Turbine (power plant)
CGE	computable general equilibrium (model)
CHP	combined heat and power (cogeneration)
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPS	Compact PRIMES model for Slovakia
EC	European Commission
EDGAR	European Commission's Joint Research Center Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
ENVISAGE	Environmental Impact and Sustainability Applied General Equilibrium (model)
ETS	emissions trading system of the European Union (also, the sectors included in the trading system)
EU	European Union
EUCO	European Council
GDP	gross domestic product
GHG	greenhouse gas(es)
GWhe	gigawatt hour equivalent
ICE	Internal Combustion Engine vehicles
IEA	International Energy Agency
LCU	local currency units
Mt	megatonne (millions of metric tons)
$MtCO_2e$	millions of metric tons of carbon dioxide equivalent
MW	megawatts
MWh	megawatt hours
NCV	net calorific value
PRIMES	Price-Induced Market Equilibrium System (energy system model)
RES	renewable energy source or renewables
Slovak-CGE	ENVISAGE-Slovakia applied general equilibrium model
Solar PV	solar photovoltaic (power plant)
toe	metric tons of oil equivalent
TWh	terawatt hours
UNFCCC	United Nations Framework Convention on Climate Change
Visegrad group	Czech Republic, Hungary, Poland and Slovakia
WDI database	World Development Indicators database (World Bank)

CONTENTS

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This report is a synthesis of analysis carried out by the World Bank in partnership with the Government of Slovakia under the Reimbursable Advisory Services project, Development of Economic Modeling Tools and Building Capacity in Modeling for Sustained Growth in Slovakia. The Ministry of Environment and its Institute for Environmental Policy partnered with the World Bank for the macroeconomic modelling and with E3-Modelling for the energy modelling.

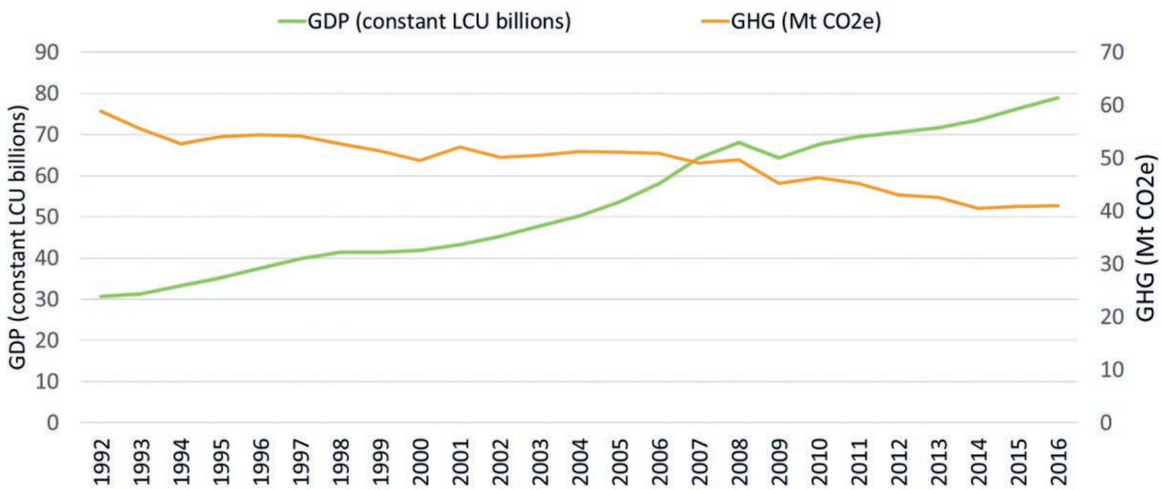
The team is particularly grateful to Norbert Kurilla, Martin Haluš, Kristína Petríková and Stella Slučiaková for their support.

The project was led within the World Bank by Donato De Rosa (task manager), Leszek Kasek (former task manager), Dinar Dhamma Prihardini (former task manager, macroeconomic modeling), Jakub Boratynski (macroeconomic modeling), Wojciech Rabiega (research assistance), Agnieszka Boratynska (technical support), and Erika Jorgensen (synthesis report).

EXECUTIVE SUMMARY

To set the stage for an examination of a low carbon growth path for Slovakia, the country's performance on greenhouse gas emissions, its obligations under the Paris Agreement and as a member of the European Union, and the need for a low carbon growth path are briefly examined. Slovakia contributes only marginally to global emissions. Its emissions have declined significantly in recent decades and seemingly delinked from economic growth (*Figure* i). Energy sector emissions, as in most countries, dominate its profile, although tempered by significant nuclear electricity generation. At the same time, industry and transport emissions have risen in importance. Slovakia has made considerable advances in energy efficiency since 1995, improving its energy intensity by more than half by 2016. However, the European Union overall has made steady progress over the same period, leaving Slovakia still with a distance to go to catch up with average EU energy intensity (*Figure ii*).

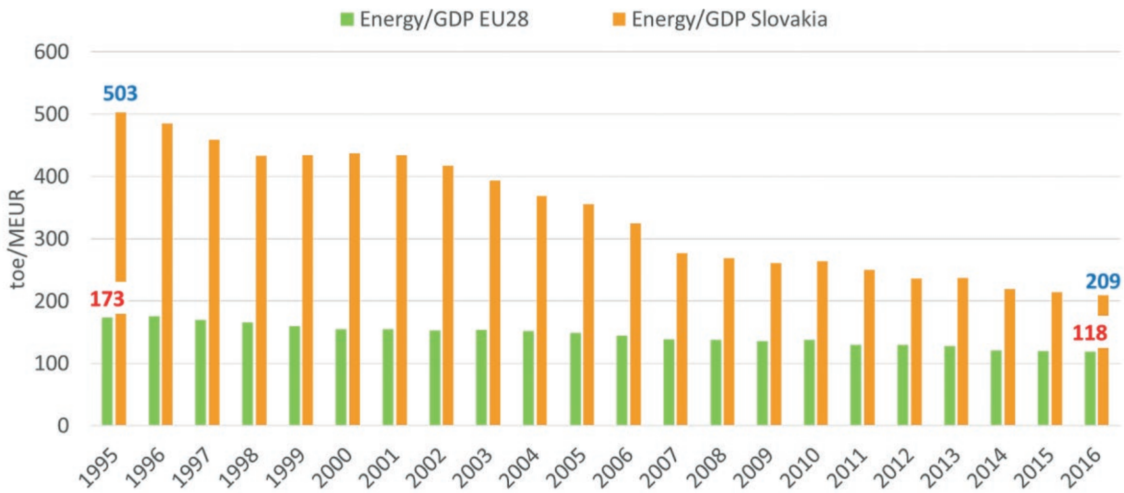
Figure i. GDP and greenhouse gas emissions, 1992-2016, in constant LCU and $MtCO_2e$
Slovakia has delinked growth from emissions



Source: GDP from WDI database, GHG from EEA database.

As part of the EU, Slovakia supports the EU's 2030 climate and energy policy framework and its contribution to the global Paris Agreement. Slovakia is part of the EU carbon market, the EU Emissions Trading System (ETS), and its emissions outside of the ETS face a Slovakia-specific target. With the 2016 'Winter Package' of measures to support the 2030 targets, Slovakia faces decisions on how to combine policy instruments aimed at renewables and energy efficiency. Given the impact of emissions reduction across the economy, policymakers in Slovakia need to define a low carbon growth path for the country. Note that a number of possible local co-benefits are not included (since they would require additional complex modeling) but could reduce the costs of a such a path.

Figure ii. Energy intensity in the EU and Slovakia, 1995-2016, in toe per € millions of GDP
Slovakia's progress in energy intensity still leaves it lagging EU averages

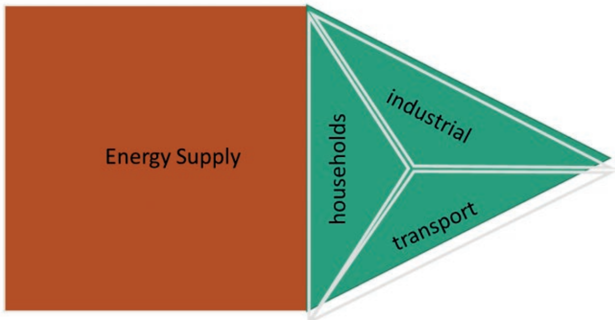


Notes: Energy intensity is a measure of energy efficiency, showing the energy needed to produce economic output. It is the ratio between gross inland energy consumption (in tons of oil equivalent) and gross domestic product (GDP) in constant millions of euros.
Source: Eurostat database.

An energy model and a macroeconomic model have been built to address questions for Slovakia about the EU's climate and energy policies. The models differ in their coverage and their approach, but together they provide a powerful tool for assessing climate policies and projecting the impact of different policy packages. Both models draw on multiple data sources and build on the information used by the EU for constructing scenarios. They share many exogenous assumptions, and their projections are consistent with each other by design.

An energy model for Slovakia captures the details of energy supply and demand that are critical to designing a low carbon path. A country-level energy model, named the Compact-PRIMES for Slovakia (CPS), provides a bottom-up technology-rich analysis of the key elements of the energy sector and has been designed to evaluate low carbon options for the energy sector. The CPS model is a single-country partial-equilibrium model of the energy sector which balances energy supply and demand. As a hybrid model with technology and engineering detail together with micro- and macroeconomic interactions and dynamics, the CPS' sectoral decisions consider technology and costs. Electricity and heat supply and biomass supply are captured on the supply side while energy demand modeling includes separate treatment of the industrial sector (and 10 subsectors), transport, and other demand. The design of the CPS model is appropriate for the quantification of long-term energy planning and policies reducing energy-related greenhouse gas emissions (*Figure iii)*.

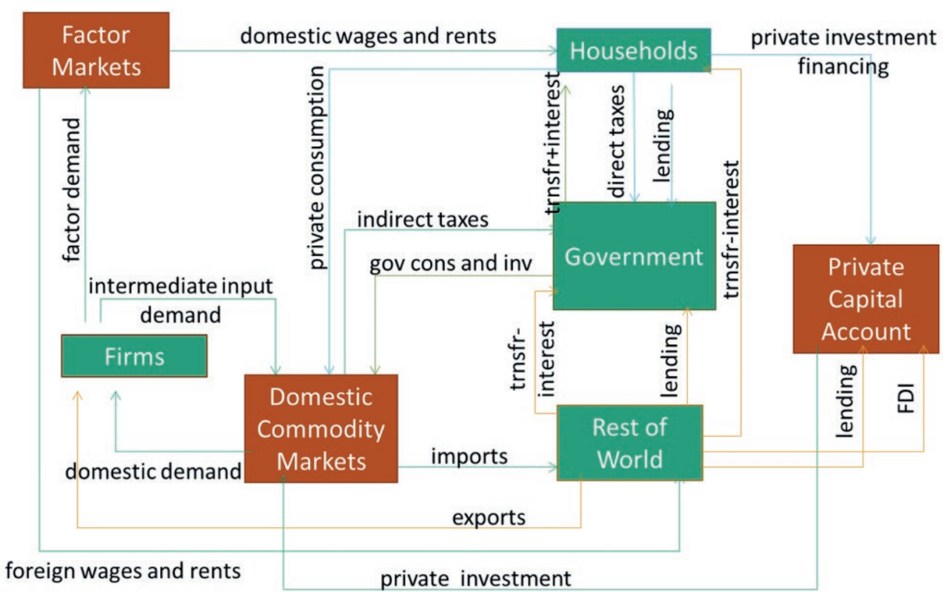
Figure iii. A simplified diagram of the Compact PRIMES for Slovakia (CPS model)
Modelling Slovakia's energy sector: supply and demand by sectors are equilibrated



Source: E3-Modelling, CPS Technical Report

A macroeconomic model for Slovakia complements the energy model, using the detailed energy system results from the CPS model and assessing economywide impacts. It has all the features of a standard computable general equilibrium model but with additional detail in energy, electricity generation, and emissions so that it is useful for the assessment of climate policies. The macroeconomic model, named the ENVISAGE-Slovakia applied general equilibrium (Slovak-CGE) model, has been customized to reflect the particular features of the Slovak economy. Importantly, demand for energy commodities across households and firms is price sensitive, and various electricity generation options are captured. Emissions are explicitly modeled. A variety of mitigation policies can be analyzed using the Slovak-CGE model. By comparison with the CPS energy model, the aim of the Slovak-CGE model is to simulate the broader economic effects of moving towards a low carbon economy (*Figure iv)*.

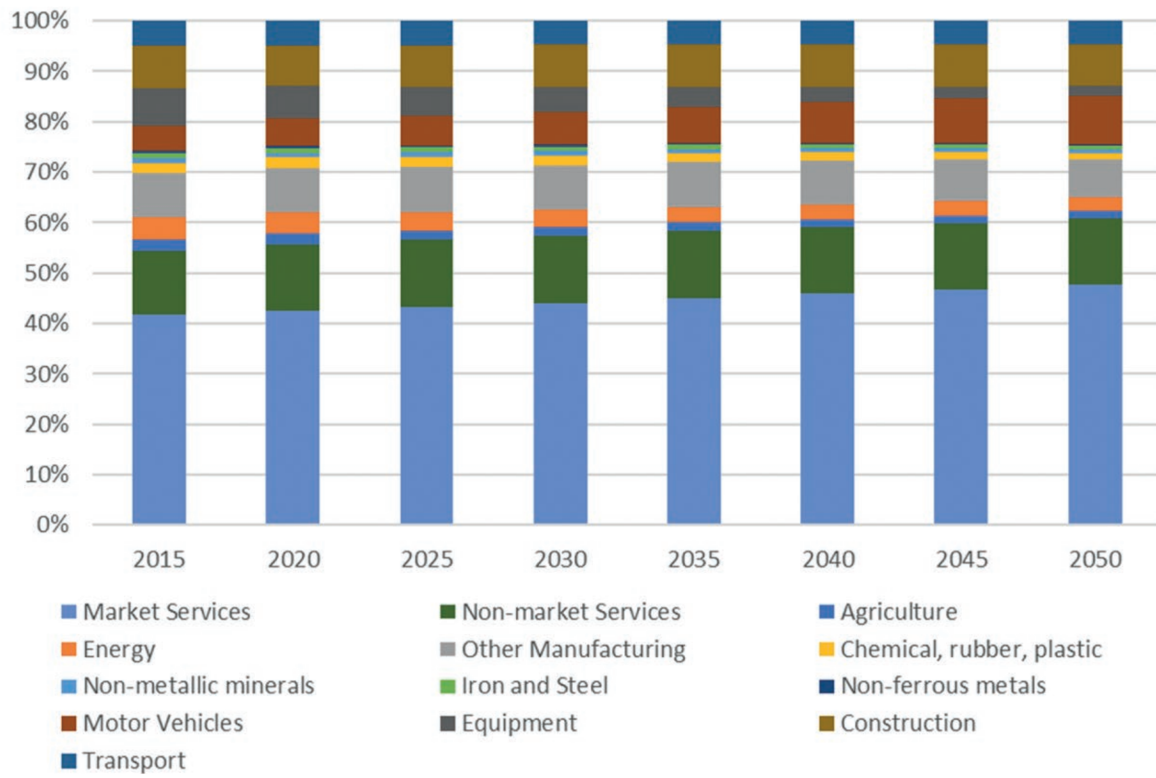
Figure iv. Simplified diagram of the ENVISAGE-Slovakia Applied General Equilibrium (Slovak-CGE) Model
A macroeconomic model captures impacts across the economy



Source: World Bank, Slovak-CGE model documentation.

A business-as-usual projection for Slovakia that includes national obligations on climate action through 2020 is set up as the reference scenario, against which other scenarios can be compared. This scenario builds on the 2016 EU Reference Scenario. The reference scenario assumes that there are no further supporting climate policies post 2020 other than the ETS but that energy efficiency improvements are sustained. GDP growth is expected to slow to 0.6 per cent per annum by 2050 in Slovakia, driven by a fall in population. Within the overall story of slowing growth, some sectors and subsectors continue to expand while others contract. For example, the projected rise in per capita incomes supports an expansion of the services sector (*Figure v*).

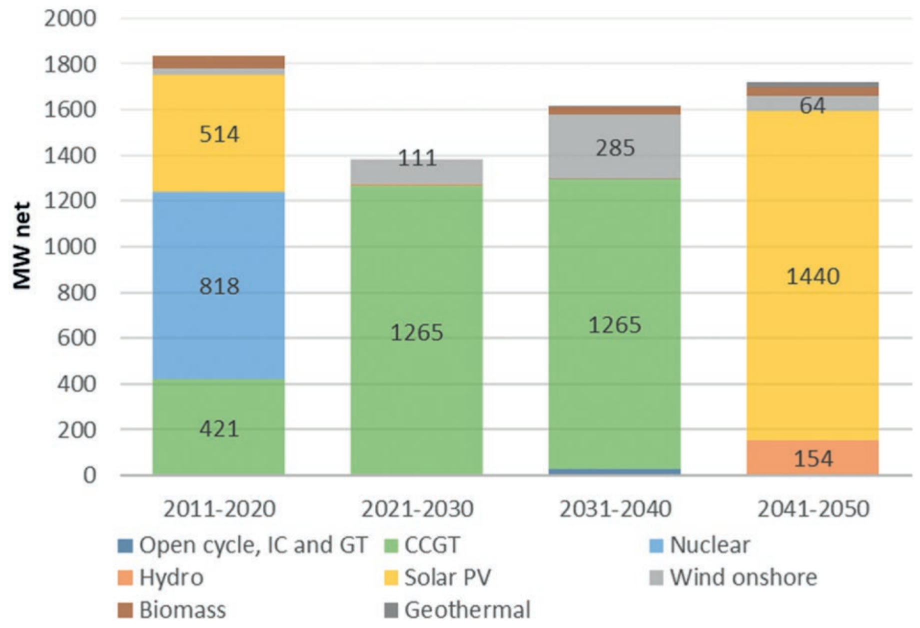
Figure v. Share of value-added by sector, reference scenario, 2015 to 2050
Services expand as per capita incomes rise in the reference scenario



Source: Slovak-CGE model results.

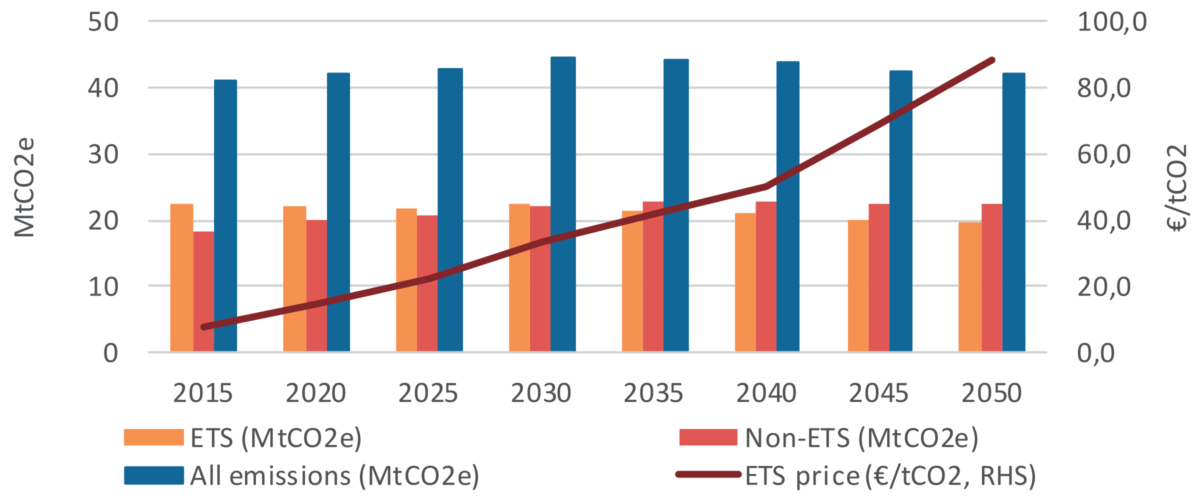
The business-as-usual or baseline scenario projects the shifting forces of energy efficiency, energy demand, and the response of energy supply to ETS and other prices. The reference scenario projects continuous energy efficiency improvements. The ETS will continue as a key influence on energy choices through 2050 in the Reference scenario. Energy demand in industry will continue to moderate in the reference scenario as new efficient technologies are embedded in productive investment in industry. ETS prices push industrial energy consumption towards less carbon-intensive fuels. Demand for electricity rises through the projection period. Nuclear energy is projected to play a crucial role in the electricity mix of Slovakia, but wind and solar do not expand substantially. Power sector investment is projected to shift over time, from nuclear to Combined Cycle Gas Turbine (CCGT) to solar (*Figure vi*). Without supporting policies after 2020, the ETS price is not sufficient to drive significant reductions in emissions (*Figure vii*).

Figure vi. Newly installed capacity in electricity, reference scenario, by decades to 2050, in net MW
Investment in electricity capacity is concentrated in CCGT in the medium term and solar in the long term in the reference scenario



Notes: Net MW is the maximum output of electricity net of power consumed within the plant.
Source: E3-Modelling, CPS Technical Report.

Figure vii. Emissions and ETS price, reference scenario, 2015 to 2050, in $MtCO_2e$ and € per metric ton
ETS price alone drives only a small reduction in total emissions in the reference scenario



Notes: All emissions is total GHG emissions excluding LULUCF.
Source: Slovak-CGE model results and CPS model results.

The European Union's 2016 'Winter Package' to support the transition to clean energy requires Member States to choose targets for energy efficiency and renewables and defend those targets. The CPS and CGE models can assist Slovakia in that task. Four decarbonization scenarios for Slovakia have been designed as contrasting combinations of energy efficiency and renewables targets, representing the trade-offs between targets (*Table i*). The policies underlying the decarbonization scenarios are focused on the energy sector. All four decarbonization scenarios necessarily focus on the energy sector, and all include construction of new nuclear generation capacity for Slovakia, sustaining the key role of nuclear energy in the generation mix. Substantial investments in energy efficiency are also needed by businesses and households to achieve reductions in energy demand (*Table ii*).

Table i. Decarbonization scenarios by renewables and energy efficiency target intensity
A simplified view of the decarbonization scenarios

Scenario Name	Renewables target	Energy efficiency target
Decarbonization 1	Basic	Ambitious
Decarbonization 2	Median	Median
Decarbonization 3	Ambitious	Basic
Decarbonization 4	Very ambitious (for electricity)	Basic

Source: E3-Modelling, CPS Technical Report.

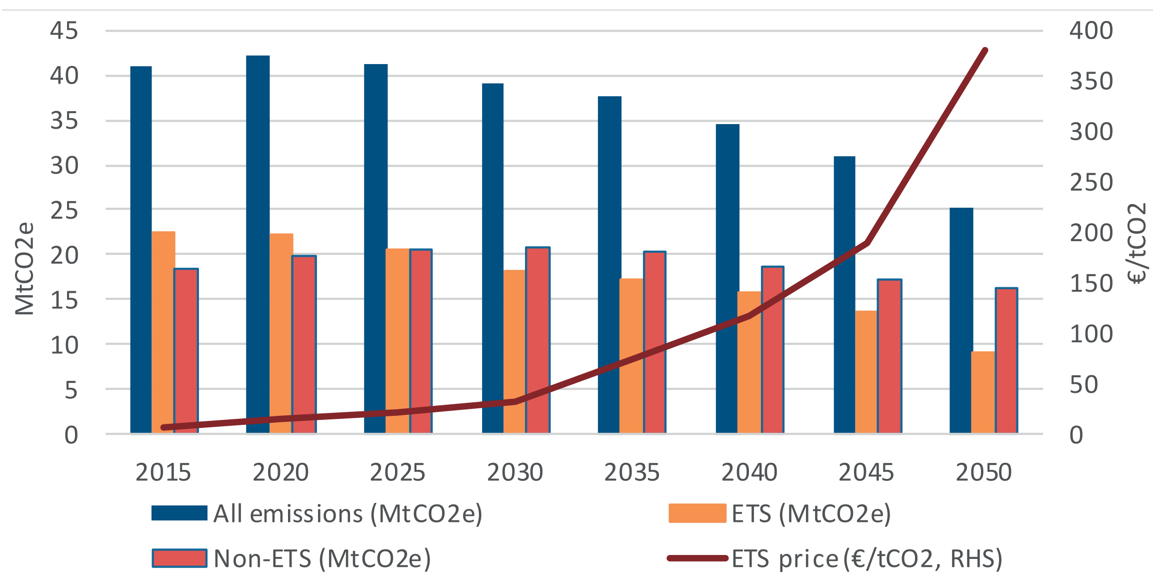
Table ii. Key policy targets and outcomes by policy scenario
Decarbonization scenarios differ on targets for renewables and energy efficiency

Policy indicators	2015	2020	2030				
			Reference	DCarb1	DCarb2	DCarb3	DCarb4
Total CO_2 emissions from energy combustion (% change from 2005)	-27.29	-27.75	-27.81	-39.02	-40.80	-40.59	-41.48
ETS sectors, CO_2 emissions from energy (% change from 2005)	-30.78	-34.88	-38.40	-50.58	-53.46	-53.51	-54.99
non-ETS sectors, CO_2 emissions from energy (% change from 2005)	-21.39	-15.71	-9.91	-19.49	-19.42	-18.77	-18.66
Overall RES share (%)	14.03	14.49	14.34	16.33	18.91	19.83	21.85
RES-H&C share (%)	14.16	13.24	14.04	16.89	20.65	22.07	19.55
RES-E share (%)	19.43	23.38	21.28	22.62	24.81	25.32	36.79
RES-T share (%)	8.26	10.05	10.20	11.49	11.74	11.80	13.12
Primary energy savings (%)	0.00	-20.16	-24.91	-30.32	-28.36	-27.25	-28.88

Notes: RES-H&C is renewable energy sources for heating and cooling. RES-E is renewables for electricity generation. RES-T is renewables in transport. Primary energy savings is compared to PRIMES 2007 baseline projections.
Source: E3-Modelling, CPS Technical Report.

Emissions from ETS sectors in Slovakia by 2050 are projected to decrease by more than half compared to the reference scenario, while other emissions fall by more than one-quarter (*Figure viii*)**.** Decarbonization implies specific policies. In all scenarios, there is a significant push by the transport sector to improve energy efficiency. Four combinations of policies were assessed (creating the four decarbonization scenarios). Up to 2030, the most important area for policy in Slovakia is renovation of buildings. All policy scenarios demonstrate the same level of tota emissions reduction. Energy consumption in the policy scenarios decreases significantly relative to the reference scenario, following also a declining trend over time. Moving from DCarb4 to DCarb1 policy scenario, the reduction of final energy demand intensifies as a result of the introduction of additional policies promoting energy efficiency improvements. In the medium term, electricity demand increases at lower rates than in the reference scenario. In the medium-term, renewable policies enable the penetration of biomass plants into the power mix, substituting for CCGT generation. The scenarios differ in their impact on Slovakia's energy system but are similar in their macroeconomic impact except for variations in investment in later years. The analysis finds impacts on GDP of up to three to four percent, with investment rising and displacing consumption. There is a significant impact on the structure of the economy; and decarbonization has varied effects across industries.

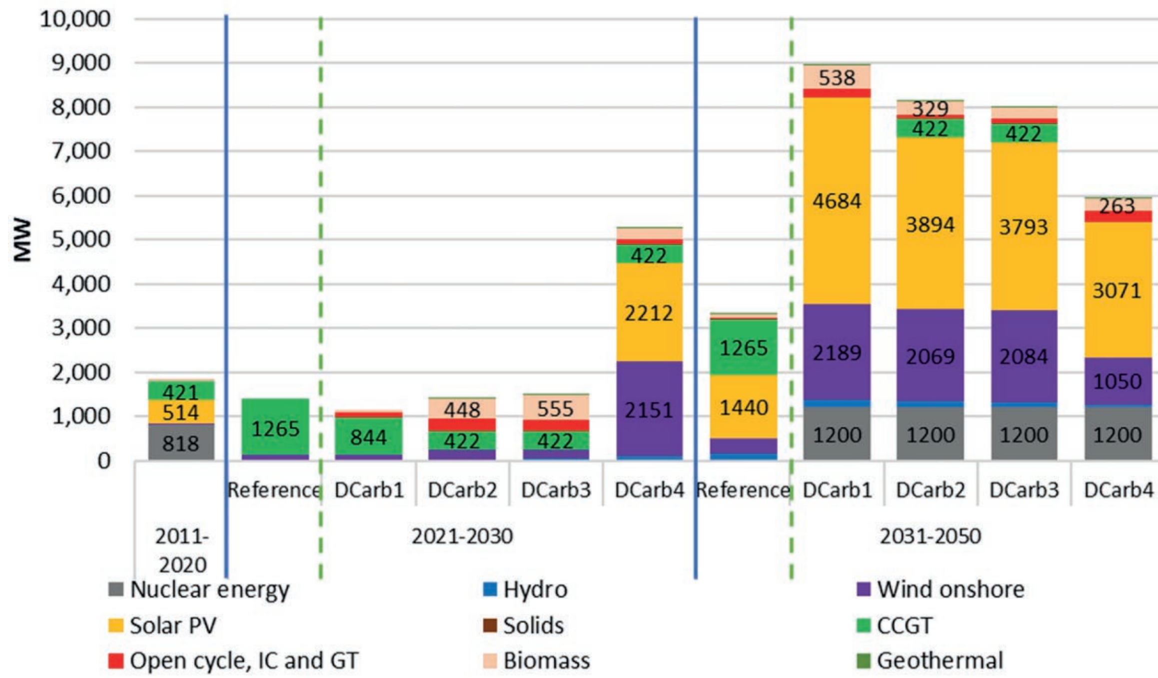
Figure viii. Emissions and ETS price, policy scenarios, 2015 to 2050, in $MtCO_2e$ and € per metric ton
Supporting policies and a high ETS price drive substantial reduction in emissions



Note: Decarbonization 4 scenario, but other policy scenarios are similar.
All emissions is total GHG emissions excluding LULUCF.
Source: Slovak-CGE model results and CPS model results.

All four decarbonization scenarios involve the construction of new nuclear generation capacity for Slovakia, continuing the importance of nuclear energy in the generation mix. This investment in nuclear displaces investment in CCGT compared with the reference scenario. The four decarbonization scenarios do differ in the extent to which renewables enter the generation mix. The importance of renewables increases from Decarbonization 1 to Decarbonization 4. In particular, Decarbonization 4 focuses on achieving the renewables target through the electricity sector and results in greater penetration of renewables, particularly wind (*Figure ix*).

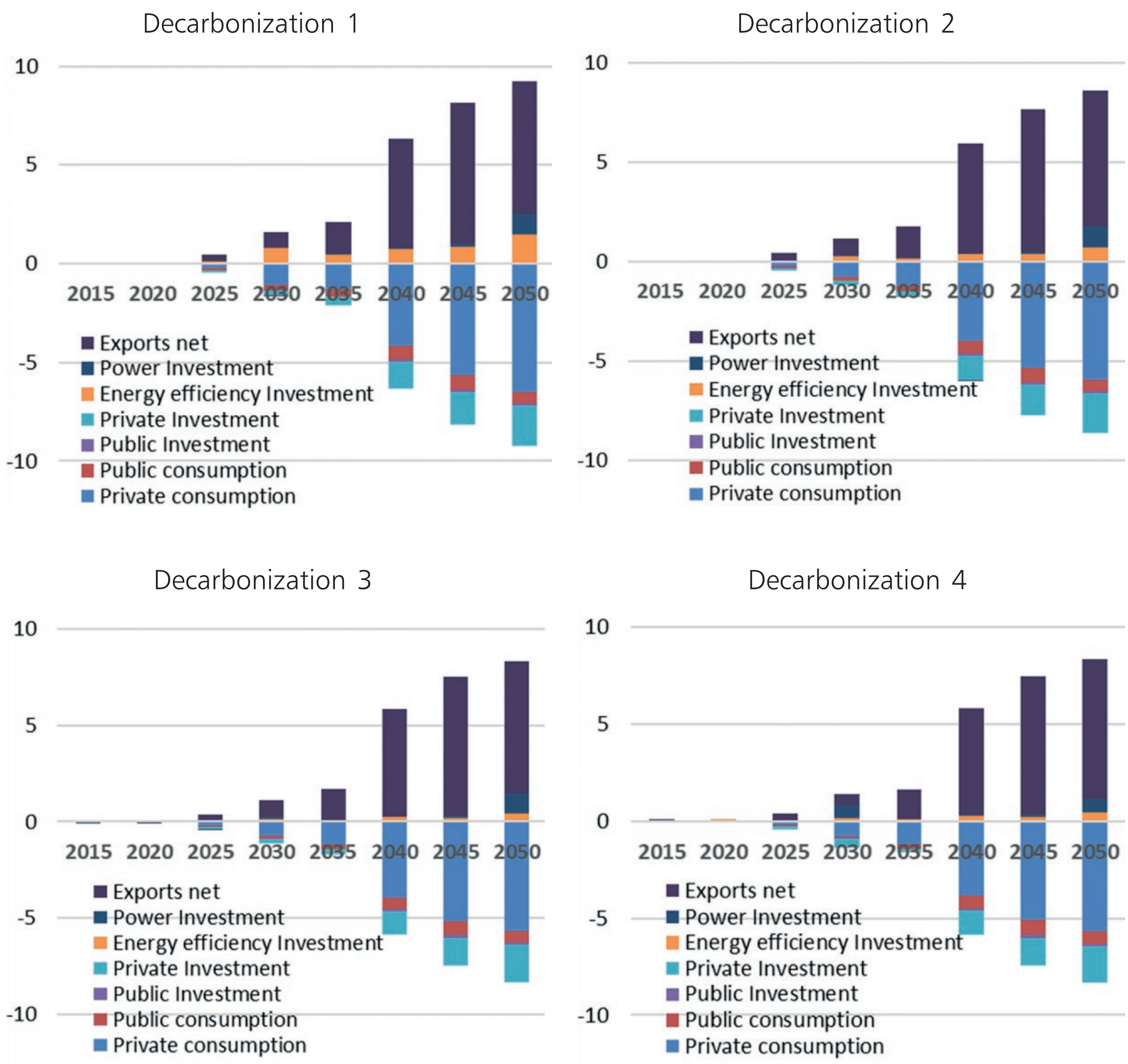
Figure ix. Newly installed capacity in electricity, by scenario, 2011-2050, in net MW
Investment in electricity capacity in the policy scenarios diverges from the reference scenario in magnitude and earlier solar PV



Source: E3-Modelling, CPS Technical Report.

Moving to a low carbon economy can support somewhat higher GDP in the long term. However, it could also lead to lower household consumption, especially during the transition when investment is higher. Decreased demand for fossil fuels reduces Slovakia's import bill. Within investment, some crowding out of non-energy investment may occur, as the country pushes forward on investing in decarbonization. The structure of aggregate demand shifts under all the scenarios, in turn affecting industry outputs; and the changes in the industrial structure of the economy leads reallocation of labor across industries. The government is assumed to increase taxes or reduce transfers to ensure sustainability of the government budget during the transition to a low carbon economy (*Figure x).*

Figure x. Change in expenditure shares in GDP relative to baseline, by scenario
Net export shares are boosted over the long-term, more than compensating for reduced consumption



Source: Slovak-CGE model results.

The scenarios generated by the CPS and CGE models show Slovakia achieving its mitigation targets rather easily. The large use of hydro resources and biomass are behind the easy achievement of the renewables target, whereas gross energy consumption grows very moderately in Slovakia due to the energy efficiency progress achieved in parallel, manifested by an improvement of the energy intensity of GDP. Despite the lack of additional policies supporting the use of renewables, the renewables share follows an ascending trend over time due to the rising EU ETS carbon prices. The ETS carbon prices affects the power sector, as well as the energy intensive industries and constitutes the main driver for the carbon emission reduction.

The policy scenarios were designed to provide a contrasting mix of targets, to assess the impacts of setting different ambitions for the renewables and energy efficiency targets. Setting renewable energy sources (RES) and energy efficiency (EE) targets is at the discretion of national policy. The range of possibilities is larger for the RES target than for the EE target. For the latter, the most important policy focus must regard the renovation of buildings, which constitute the most important source of possible energy savings until 2030. The potential of savings in industry and transport, which are also significant, can only be deployed in the longer-term. For renewables, there exists a trade-off between developing biomass or variable RES in the power sector. However, both are needed to develop significantly if the RES target is chosen at an ambitious level.

The analysis undertaken via modelling of the macroeconomy and the energy sector as well as other investigation identified possible low carbon growth paths for Slovakia but also identified issues that merit strategic consideration by policymakers. These issues are likely to include: gaps in data and knowledge, uncertainties such as the speed of technological change and future global and regional developments, and a variety of tradeoffs related to the costs of mitigation actions, implementation difficulty, timing, and many others. The energy and macroeconomic models should serve as valuable tools for ongoing assessment of mitigation options for Slovakia.

The newly-adopted EU targets of 32 percent for renewables and 32.5 percent for energy efficiency in 2030 are higher than assumed in this analysis. The European Union has now adopted targets of 32 percent for RES and 32.5 percent for EE, higher than the targets assumed in the policy scenarios modelled here. In response, Slovakia will likely need to adopt ambitious targets for both RES and EE, for example 22 percent for RES and 30 percent for energy efficiency.

Photo: High Tatras Mountains, Pleso, Slovakia, by Max Pixel, N.D. [Creative Commons Zero - CC0.]

CHAPTER 1

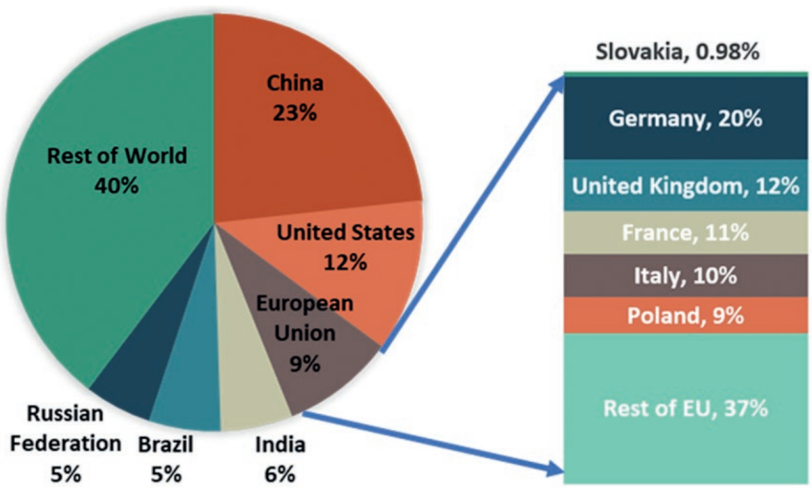
INTRODUCTION AND BACKGROUND

To set the stage for an examination of a low carbon growth path for Slovakia, the country's performance on greenhouse gas emissions, its obligations under the Paris Agreement and as a member of the European Union, and the need for a low carbon growth path are briefly examined. Slovakia contributes only marginally to global emissions. Its emissions have declined significantly in recent decades and seemingly delinked from economic growth. Energy sector emissions, as in most countries, dominate its profile, although tempered by significant nuclear electricity generation. At the same time, industry and transport emissions have risen in importance. As part of the EU, Slovakia supports the EU's 2030 climate and energy policy framework and its contribution to the global Paris Agreement. Slovakia is part of the EU carbon market, the EU Emissions Trading System (ETS), and its emissions outside of the ETS face a Slovakia-specific target. With the 2016 'Winter Package' of measures to support the 2030 targets, Slovakia faces decisions on how to combine policy instruments aimed at renewables and energy efficiency. Given the impact of emissions reduction across the economy, policymakers in Slovakia need to define a low carbon growth path for the country. Note that a number of possible local co-benefits are not included (since they would require additional complex modeling) but could reduce the overall costs of a low carbon growth path.

SLOVAKIA'S GREENHOUSE GAS EMISSIONS

Before considering a path forward, it is worth taking a look at some key facts about Slovakia's greenhouse gas emissions, its energy sector, and its economy. Slovakia is a small country and contributes only marginally to the global carbon footprint, with total GHG emissions of 41 $MtCO_2e$ (million metric tons of carbon dioxide equivalent) in 2016 or less than 0.1 percent of global emissions.[1] The European Union as a whole contributes about eight percent of global emissions (or 4,441 $MtCO_2e$ in 2016), of which Slovakia's emissions constitute less than one percent. More importantly, Slovakia's per capita emissions are also modest. At 6.8 metric tons of carbon dioxide equivalent per person in 2016, Slovakia matches the European Union average (although the world average stands lower at 4.8 metric tons per capita).[2] Nevertheless, Slovakia has made regional and global commitments to reduce its emissions. (*Figure 1*).

Figure 1. Global emissions by selected countries and EU member states' emissions, % of totals
Slovakia's GHG emissions constitute a small share of global and EU emissions



Notes: GHG emissions excluding LULUCF from 2012.
Source: World Development Indicators.

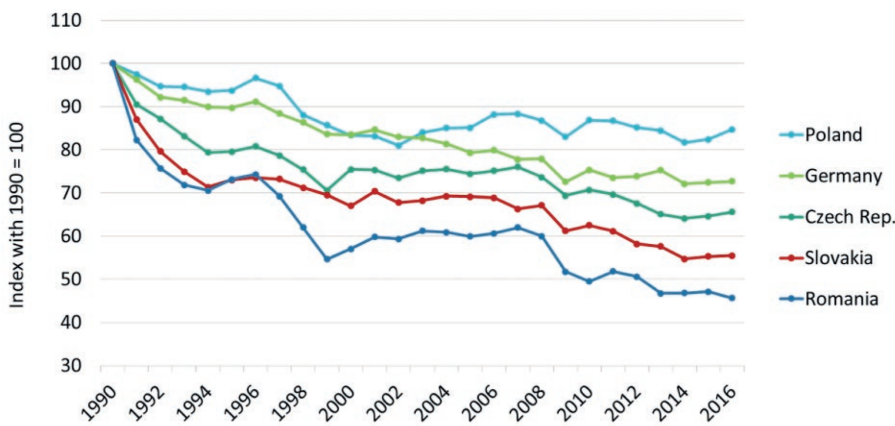
As happened generally across formerly socialist economies, Slovakia's transition to a market economy had a co-benefit of sharply reduced carbon emissions. Slovakia's greenhouse gas emissions have fallen significantly in the last few decades. From 74 million metric tons of carbon dioxide equivalent in 1990, Slovakia's GHG emissions fell by 45 percent by 2016. Even within Eastern Europe, where the closure of inefficient highly energy-intensive industrial plants during the transition to a market economy caused emissions to plummet, this was a strong performance. (*Figure 2*).

1. Slovakia's total greenhouse gas emissions for 2016 excluding LULUCF (land use, land use change, and forestry) is from UNFCCC. The country's 2016 emissions including LULUCF were 34 $MtCO_2e$ while the European Union's emissions including LULUCF in 2016 were 4,002 $MtCO_2e$. Global greenhouse gas emissions for 2016 excluding LULUCF is an estimate from EDGAR (European Commission's Joint Research Center Emissions Database for Global Atmospheric Research).

2. Joint Research Center, Emissions Database for Global Atmospheric Research, 2016.
edgar.jrc.ec.europa.eu/overview.php?v=CO2andGHG1970-2016&dst=CO2pc.

Figure 2. Changes in GHG emissions in Slovakia and four other EU countries, 1990 to 2016, index

Slovakia's emissions have declined significantly

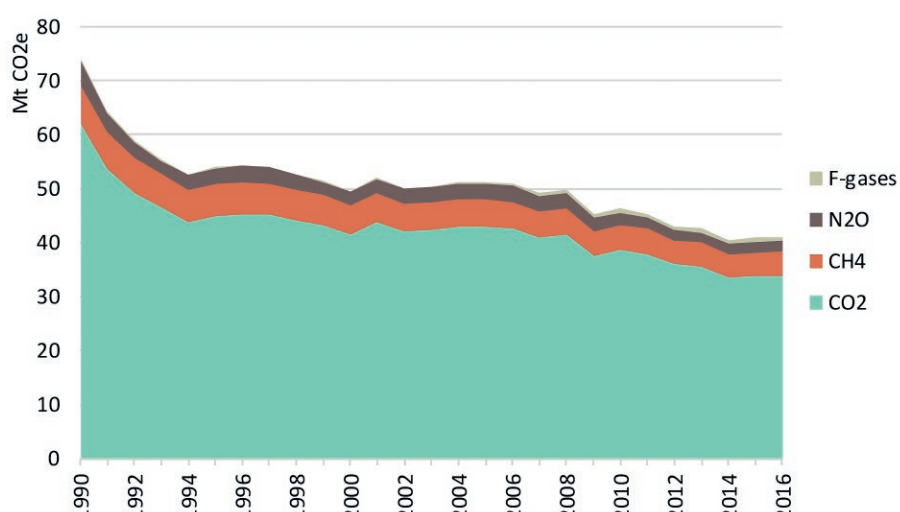


Source: World Bank staff calculations based on EEA database.

Within Slovakia's declining emissions, its energy sector continues to dominate, but industry and transport emissions have risen in importance. The country's emissions continue to be mostly CO_2. (*Figure 3*). The sectoral trend in Slovakia's emissions profile has been driven by the dramatic reduction of emissions from the energy sector, while those in other sectors have remained relatively unchanged, together driving down the share of emissions from energy (excluding transport) from two-thirds of total emissions in 1990 to about half in 2016. Within energy emissions, about 60 percent come from coal-based electricity and heat generation. Industrial processes account for about one-quarter of today's emissions. They are generated mainly in production of metal products (about half of industrial emissions) and minerals (about one-quarter) (*Figure 4*).

Figure 3. Greenhouse gas emissions by gas, 1990 to 2014, in Mt of CO_2e

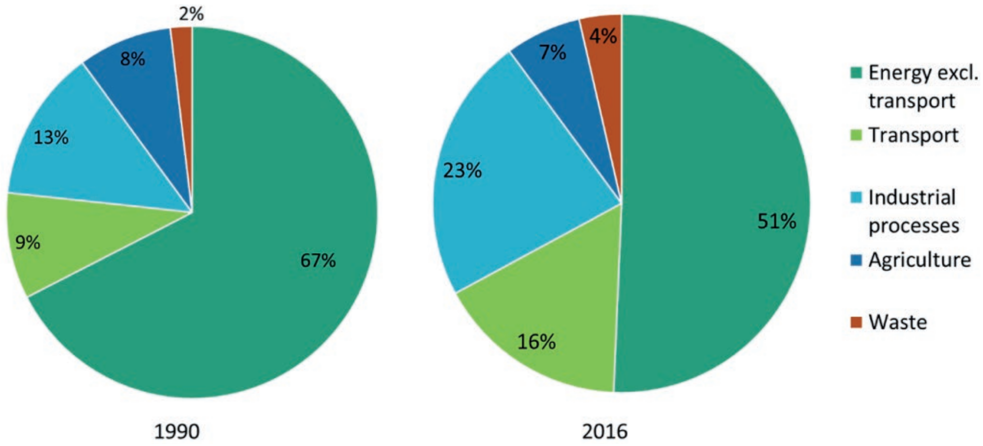
CO_2 is Slovakia's dominant greenhouse gas



Notes: F-gases are fluorinated gases; N2O is nitrous oxide; CH4 is methane; CO2 is carbon dioxide.

Source: World Bank staff calculations based on EEA database.

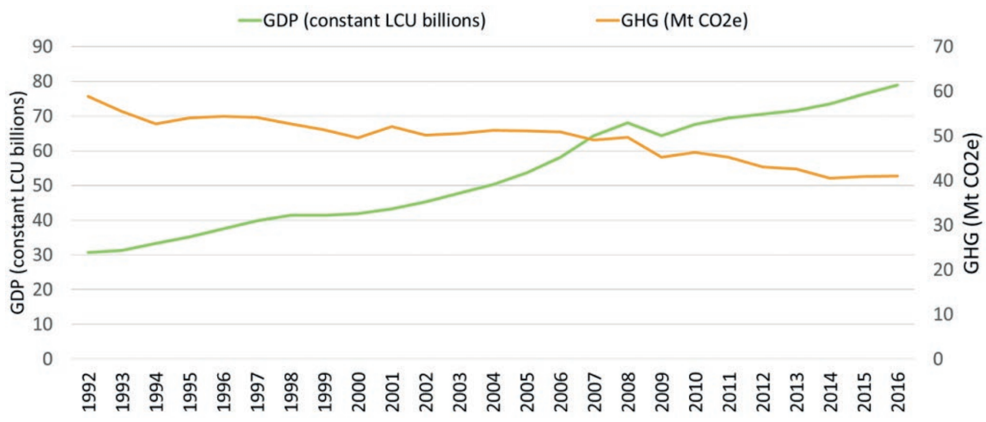
Figure 4. Greenhouse gas emissions by sector, 1990 and 2016, in % of total
Industry and transport emissions have grown in importance



Source: World Bank staff calculations based on EEA database.

Importantly, Slovakia has made significant progress on delinking economic growth from emissions of greenhouse gases. From about 60 million metric tons of CO_2 equivalent in 1992, Slovakia's emissions contracted at a slow but steady pace while output and income rose at a faster pace. At the same time, Slovakia's manufacturing sector was expanding to about a third of gross value added by 2010, nearly a 10 percent increase from 1995. Further, the share of gross value-added of financial intermediation and real estate services fell from 20 percent in 1995 to 15 percent in 2010.[3] These trends would tend to push up GHG emissions, but Slovakia's emissions continued steadily downward, demonstrating a delinking of growth from emissions that, unusual even in Eastern Europe, has continued unabated (*Figure 5*).

Figure 5. GDP and greenhouse gas emissions, 1992-2016, in constant LCU and $MtCO_2e$
Slovakia has delinked growth from emissions



Source: GDP - WDI database, GHG - EEA database.

3. Gill, Indermit S.; Raiser, Martin. 2013. *Golden growth: restoring the lustre of the European economic model (Vol. 3): Country benchmarks (English)*. Europe and Central Asia Studies. Washington DC: World Bank. http://documents.worldbank.org/curated/en/394981468251372492/Country-benchmarks.

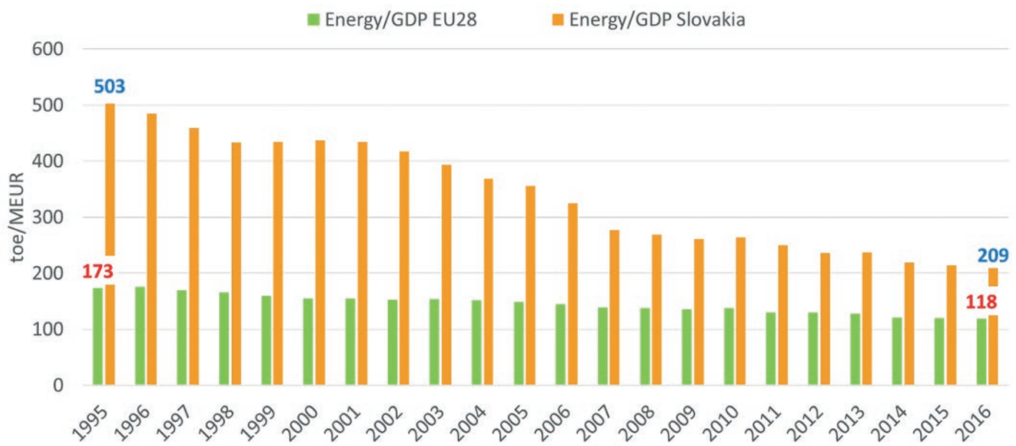
Slovakia's progress in delinking stands out among its European peers. While real annual GDP growth in the countries of the European Union averaged about 2.5 percent during 1995 to 2016, Slovakia registered 3.9 percent average growth. The other countries of the EU emitted about 17 percent less in greenhouse gases in 2016 than in 1995, but Slovakia's emissions fell by 24 percent (*Figure 6*).

Figure 6. Growth in emissions and GDP, EU and others, 1995-2016 in %
Slovakia's growth has been well above average within the EU while its emissions have risen relatively modestly

Notes: Countries are EU member states plus Iceland and Switzerland and without Malta. Emissions growth is total change in % from 1995 to 2016. GDP growth is average annual change in real GDP from 1995 to 2016.
Sources: Emissions data based on EEA data (UNFCCC); GDP from Eurostat.

Slovakia has made considerable advances in energy efficiency since 1995. Starting at more than 500 tons of oil equivalent required for every hundred million euros of output in 1995, the country's energy intensity has fallen by more than half to near 200 in 2016. Meanwhile, the European Union overall has made steady albeit less dramatic progress over the same period, improving energy intensity by about one-third. From a level of energy intensity that was three times higher than the EU average, Slovakia has progressed to a level less than double that of the EU. Yet Slovakia still has a way to go to reach even average EU energy intensity (*Figure 7)*.

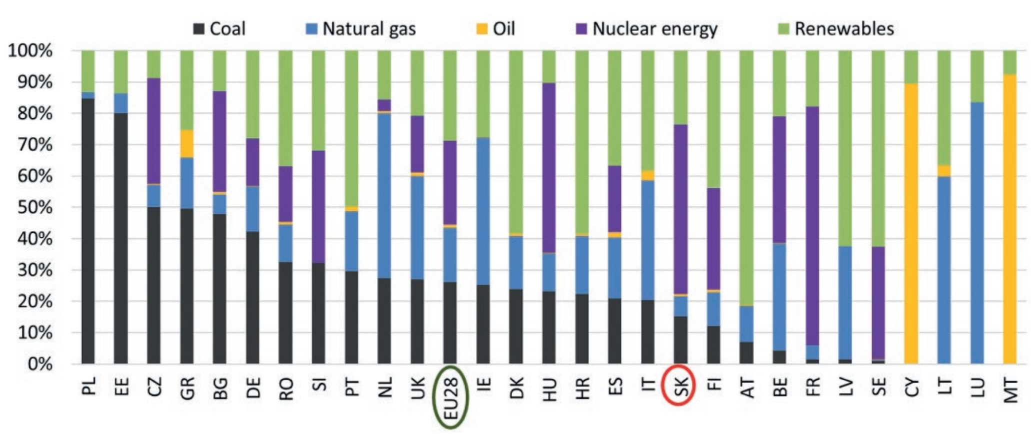
Figure 7. Energy intensity in the EU and Slovakia, 1995-2016, in toe per € millions of GDP
Slovakia's progress in energy intensity still leaves it lagging EU averages



Notes: Energy intensity is a measure of energy efficiency, showing the energy needed to produce economic output. It is the ratio between gross inland energy consumption (in tons of oil equivalent) and gross domestic product (GDP) in constant millions of euros.
Source: Eurostat database.

For electricity generation, Slovakia depends mostly on nuclear power, far above EU averages. Slovakia generates 54 percent of its electricity from nuclear power, 24 percent from renewables, 15 percent from coal, and six percent from natural gas. Within renewables, almost 18 percent is hydro, about four percent is biomass and about two percent is solar. Poland has the most emissions-intensive electricity sector, with 85 percent coming from coal-fueled power plants. France has the largest share of nuclear power, generating 76 percent of its electricity, while Austria has the largest share of renewables in power, with 81 percent. The European Union on average generates 29 percent of its electricity from renewables, 27 percent from nuclear energy, and 26 percent from coal (*Figure 8)*.

Figure 8. Gross electricity generation by source, Slovakia and EU members, 2015, % of total GWhe
Slovakia depends mostly on nuclear power for electricity



Note: GWhe is gigawatt hour equivalent. Renewables include biomass-waste; hydro (pumping excluded); wind; solar; geothermal and other renewables.
Source: EU Reference Scenario 2016.

THE PARIS AGREEMENT AND CLIMATE ACTION IN THE EUROPEAN UNION

In October 2014, the European Council adopted an ambitious 2030 climate and energy policy framework for the EU, to help pave the way for the Paris Agreement. The policy package sets a binding target to reduce EU domestic greenhouse gas emissions by at least 40 percent below 1990 levels by 2030. This target aims to ensure that the EU is on a cost-effective track towards meeting its objective of cutting emissions by at least 80 percent by 2050. In addition to the target for overall cuts, the Framework also sets out targets of at least a 27 percent share for renewable energy and at least a 27 percent improvement in energy efficiency. The EU's overall mitigation target under the 2030 climate and energy framework was submitted to the UNFCCC in 2015 as its Nationally Determined Contribution under the Paris Agreement.

The European Union's emissions trading system (ETS) is the cornerstone of the EU's commitment to mitigation and its key tool for reducing emissions cost-effectively. It is the world's first major carbon market, and it remains the biggest one. To achieve the overall 40 percent target set in the 2030 Framework, sectors covered by the EU ETS, which constitute about 45 percent of EU emissions, would have to reduce their emissions by an estimated 43 percent compared to 2005 (while emissions from sectors outside the EU ETS would need to be cut by about 30 percent below the 2005 level). A 43 percent greenhouse gas reduction target in 2030 in the ETS translates into a cap on emissions allowances in the ETS that declines by 2.2 percent annually from 2021 onwards, instead of the rate of 1.74 percent up to 2020 set by the 2020 package (*Box 1*).

Photo: Apollo Bridge architecture, Bratislava, Slovakia [https://www.goodfreephotos.com]

Box 1. The EU Emissions Trading System (EU ETS)

The centerpiece of EU climate policy is European emissions trading

The ETS provides an EU-wide limit on greenhouse gas emissions. First launched in 2005[4], the EU ETS is a regional (multi-country) system for trading GHG emission allowances. It is the first and largest greenhouse gas trading scheme in the world, now covering about 45 percent of the EU's GHG emissions. The system works on the "cap and trade" principle, in which a limit is set on the total amount of GHG emissions and the 11,000 or so heavy energy-using installations (in power generation and energy-intensive industry), who are required to participate, must secure emission allowances to cover their own emission and can trade with one another as needed. The ETS covers carbon dioxide emissions from power and heat generation; energy-intensive industry sectors including oil refineries, steel works and production of iron, aluminum, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals; and from civil aviation. Also covered is nitrous oxide from production of nitric, adipic, glyoxal and glyoxylic acids; and perfluorocarbons from aluminum production.

The EU ETS is divided in three trading periods. The first period covered the period 2005-2007 and constituted 'learning by doing' by establishing national caps and mostly free allocation of allowances. In phase two (2008-2012) which coincided with the first commitment period of the Kyoto Protocol, three additional countries (Iceland, Liechtenstein and Norway) joined. Additional greenhouse gases were included so that all the main GHGs were covered. The system was extended to the aviation sector (in 2012). More auctioning of allowances occurred although some free allocation continued. The third phase of EU ETS runs from 2013 to 2020 and cuts allowances to reduce GHG emissions by 2020 by 21 percent compared to 2005. More harmonized rules have been put in place, in particular:

i) a single, EU-wide cap on emissions (replacing national caps);

ii) for each year after 2013, the overall cap decreases annually by 1.74 percent of the average total quantity of allowances issued annually during 2008-2012;

iii) auctioning (rather than free allocation) as the default method for allocating allowances (and up to half of allowances are expected to be auctioned during phase three); and

iv) about 90 percent of allowances will be distributed to EU member states (based on emissions shares in 2005), and at least half of auctioning revenues must be used by member states for climate and energy related purposes such as energy efficiency, renewables, research, and sustainable transport.

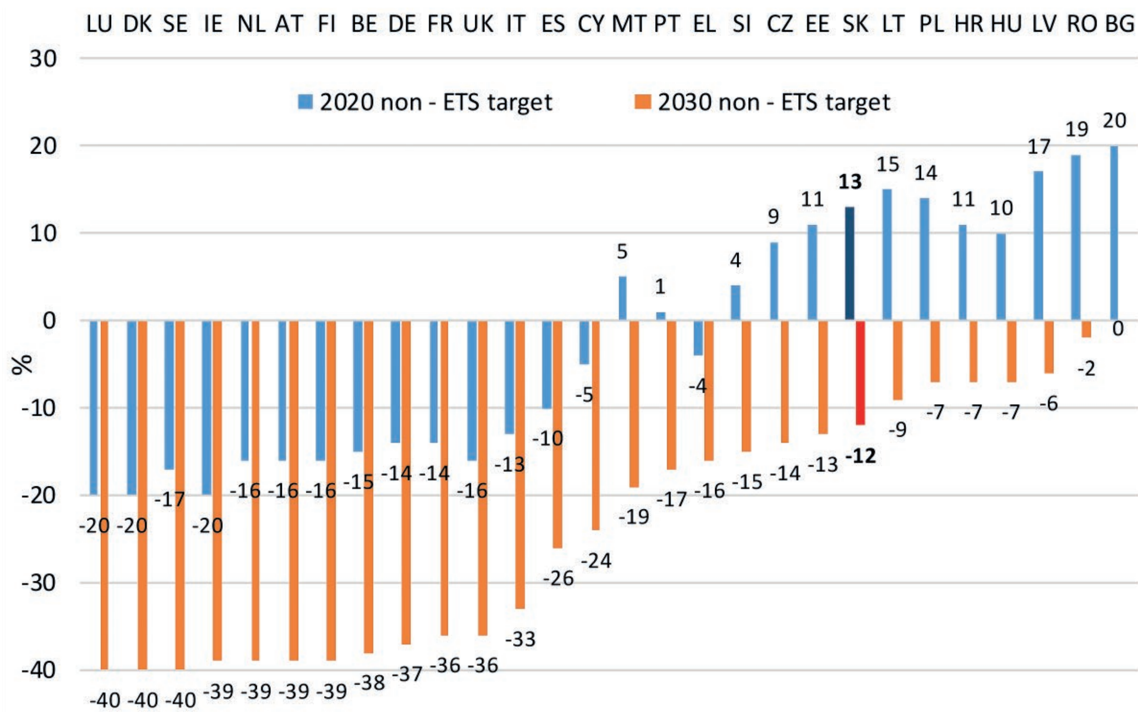
Sources: European Commission (2015), "The EU Emissions Trading System (EU ETS)", Climate Action, http://ec.europa.eu/clima/policies/ets/index_en.htm.

EU Member States have individual binding annual greenhouse gas emission targets for 2021-2030 for those sectors of the economy that fall outside the scope of the EU ETS. Sectors outside of the ETS, the "non-ETS," include small energy or industrial emitters and the transport, agriculture, services, and residential and commercial buildings sectors. This part of the economy is important for reducing emissions since non-ETS sectors account for about 55 percent of total EU emissions. While the 43 percent ETS target (relative to 2005 emissions levels) is uniform for the entire EU, the 30 percent non-ETS target (relative to 2005 emissions levels) is differentiated for the 28 member states. In May 2018, the European Parliament

4. The ETS was set out in Directive *2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community.*

adopted a regulation that translates the non-ETS commitment into binding targets for each member state for the period 2021–2030, based on the principles of fairness, cost-effectiveness and environmental integrity. Targets for non-ETS emissions in 2030 compared to 2005 range from zero percent change in emissions for Bulgaria to -40 percent for Sweden. Slovakia has a target of -12 percent[5] (*Figure 9*).

Figure 9. Non-ETS targets for EU members for 2020 and 2030 relative to 2005, in percent
Slovakia faces EU targets for non-ETS sectors aligned with its economic conditions



Source: World Bank based on EEA data and EC (May 2018).

The 2016 'Winter Package' of measures aims to advance the clean energy transition and help the EU meet its overall emissions target as well as its renewables and energy efficiency goals. The European Commission launched "Clean Energy for All Europeans," nicknamed the 'Winter Package,' in November 2016. The Winter Package provides a legislative framework to facilitate clean energy and enable the EU to meet its Paris Agreement commitments. Its main goals are: putting energy efficiency first, achieving EU global leadership in renewables, and providing a fair deal for energy consumers. It includes eight legislative proposals covering energy performance in buildings (adopted into law June 2018), renewable energy, energy efficiency, governance, electricity market design, and regulatory rules.[6]

Member states have obligations under the Winter Package. The Package sets out objectives for 2030--emissions, efficiency and renewable energy targets--defined at the level of the EU. The Winter Package legislation requires member states to define their own targets for efficiency and renewables, provided that the

5. European Union Effort Sharing Regulation for up to 2030, May 2018. data.consilium.europa.eu/doc/document/PE-3-2018-INIT/en/pdf. European Union Decision for Effort Sharing up to 2020, April 2009. eur-lex.europa.eu/eli/dec/2009/406/oj.

6. European Commission, "Clean Energy for All Europeans." ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans

targets are sufficiently ambitious with respect to the resources and capabilities of the member state and that the national targets taken for all member states are compatible with the overall targets adopted for the EU as a whole. Therefore, various levels and combinations of national targets are possible that would be consistent with the overall EU targets. Member states need to submit to the EU their targets and the related policy instruments that would drive the achievement of the targets. Moreover, member states must also submit an impact assessment of the policy instruments.

For the long-term, the European Union has laid out a vision for mitigation through 2050. A "Roadmap for Moving to a Competitive Low Carbon Economy in 2050" was published in March 2011 by the European Commission.[7] Scenarios were created by combining the four main decarbonization options – energy efficiency, renewable energy, nuclear, and carbon capture and storage. The Roadmap set out long-term objectives for EU mitigation: overall emissions for the EU are to drop by 79 to 82 percent, while emissions in the power sector are to disappear (-93 to -99 percent reductions). The Roadmap remains a long-term vision, not a policy proposal, but this objective has been reiterated by the EU in the context of its March 2015 offer to the UNFCCC, and the 2030 package is consistent with an emissions path that could get the EU to -80 percent by 2050 (*Table 1*).

Table 1. Proposed emissions reduction for the EU under the 2050 Roadmap
The EU has set a long-term objective to cut emissions dramatically by 2050

GHG reductions compared to 1990	2005 (actual)	2030	2050
Total	-7%	-40 to -44%	-79 to -82%
By sector:			
Power (CO_2)	-7%	-54 to -68%	-93 to -99%
Industry (CO_2)	-20%	-34 to -40%	-83 to -87%
Transport (incl. CO_2 aviation, excl. maritime)	30%	+20 to -9%	-54 to -67%
Residential and services (CO_2)	-12%	-37 to -53%	-88 to -91%
Agriculture (non-CO_2)	-20%	-36 to -37%	-42 to -49%
Other non-CO_2 emissions	-30%	-72 to -73%	-70 to -78%

Source: European Commission (2011).

7. European Commission (2011). A Roadmap for Moving to a Competitive Low Carbon Economy in 2050. COM/2011/0112 final. Brussels. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0112.

THE CHALLENGE OF LOW CARBON GROWTH

GHG abatement targets for the Slovak Republic are part of the EU 2030 package. Like every member state, Slovakia participates in the ETS. The high emissions intensity of the Slovakian economy argues that economic adjustment costs for energy-intensive (or ETS) sectors are likely to be high, but that intensity also may indicate that the country has a large potential for cost-efficient reduction in emissions (if adequate and well-informed policies and investments are implemented). Then, it faces non-ETS targets. According to the EC's July 2016 impact assessment,[8] Slovakia's non-ETS targets are relatively high. Slovakia, despite having one of the best performing EU economies since the global financial crisis, is expected to meet and exceed its 13 percent non-ETS target for 2020 by a large margin. (As of 2017, non-ETS emissions stand 23 percent below 2005). The country's reduction target for 2030 for non-ETS, a reduction in GHG emissions by 12 percent relative to 2005, may present some challenge.

Slovakia needs to propose how it will meet its non-ETS target, set targets for energy efficiency and renewable energy, and propose how to meet them. Its non-ETS target for 2030 is -12 percent compared to 2005 but reaching that target will require effort. The European Union's recent projection of Slovakia's economy placed non-ETS emissions below the required 12 percent cut by 2030, but other assessments (for example, the one that follows in this report) propose higher non-ETS emissions without additional action.[9] Further, policymakers must set targets for energy efficiency and renewable energy in accordance with the Winter Package. They also must decide on national policy instruments that will ensure Slovakia meets these targets, supported by evidence from an impact assessment.

More broadly, policymakers in Slovakia need to define a low carbon growth path for the country. In making national decisions about energy and climate, policymakers need to understand the likely impact of the ETS carbon market, with its required 40 percent reduction in emissions by 2030, on Slovakia's output, income, and competitiveness. They need to understand interactions with policy choices they might make for non-ETS sectors and for energy efficiency and renewables. What are the cost-effective (cheapest) policies to decrease emissions? What would be the impact on output and employment in different sectors? What would be the total costs of such a transition? This report summarizes the findings of extensive energy and macroeconomic modeling which aims to assist with these obligations, by providing the technical tools to assess packages of actions and their impacts on Slovakia's emissions, energy sector, and overall economy.

The focus of the analysis summarized in this report is on the economic impacts of a low carbon growth path but, given the complexities and uncertainties involved, without inclusion of a number of possible local co-benefits that could reduce overall costs. Such benefits may reduce the costs of low carbon policy choices. For example, green tax reform proposes that higher tax revenues from a carbon tax might be used to reduce income taxes on labor which then, in turn, can reduce informality, broaden the tax base, and even boost growth. Further, policies that shift away from fossil fuels can provide benefits in terms of health, congestion, and road safety. Such benefits, which would require significant and complex additional modeling to quantify their impact for Slovakia, are not included in this analysis but, at a conceptual level, will likely be familiar to policy makers as they choose Slovakia's policies.

8. European Commission, Impact Assessment, July 2016.

9. The EU Reference Scenario 2016 projects Slovakia's non-ETS GHG emissions to be 12.5 percent below 2005 levels in 2030. The energy model in this report projects non-ETS CO_2 emissions from energy at less that ten percent below 2005 levels by 2030, indicating that greater effort will be needed.

CHAPTER 2

MODELS TO IDENTIFY A LOW CARBON GROWTH PATH

An energy model and a macroeconomic model have been built to address questions for Slovakia about the EU's climate and energy policies. The models differ in their coverage and their approach, but together they provide a powerful tool for assessing climate policies and projecting the impact of different policy packages. Both models draw on multiple data sources and build on the information used by the EU for constructing scenarios. They share many exogenous assumptions, and their projections are consistent with each other by design.

An energy model for Slovakia captures the details of energy supply and demand that are critical to designing a low carbon path. A country-level energy model, named the Compact-PRIMES for Slovakia (CPS), provides a bottom-up technology-rich analysis of the key elements of the energy sector and has been designed to evaluate low carbon options for the energy sector. The CPS model is a single-country partial-equilibrium model of the energy sector which balances energy supply and demand. As a hybrid model with technology and engineering detail together with micro- and macroeconomic interactions and dynamics, the CPS' sectoral decisions consider technology and costs. Electricity and heat supply and biomass supply are captured on the supply side while energy demand modeling includes separate treatment of the industrial sector (and 10 subsectors), transport, and other demand. The design of the CPS model is appropriate for the quantification of long-term energy planning and policies reducing energy-related greenhouse gas emissions.

A macroeconomic model for Slovakia complements the energy model, using the detailed energy system results from the CPS model and assessing economywide impacts. It has all the features of a standard computable general equilibrium model but with additional detail in energy, electricity generation, and emissions so that it is useful for the assessment of climate policies. The macroeconomic model, named the ENVISAGE-Slovakia applied general equilibrium model (Slovak-CGE model), has been customized to reflect the particular features of the Slovak economy. Importantly, demand for energy commodities across households and firms is price sensitive, and various electricity generation options are captured. Emissions are explicitly modeled. A variety of mitigation policies can be analyzed using the Slovak-CGE model. By comparison with the CPS energy model, the aim of the Slovak-CGE model is to simulate the broader economic effects of moving towards a low carbon economy.

FOCUSING ON ENERGY WHILE ASSESSING ECONOMY-WIDE IMPACTS

To consider the issues for Slovakia raised by the EU's climate and energy policies, an energy model and a macroeconomic model have been created. The energy and macroeconomic models complement each other and when used together can assess the effects of decarbonization on both the energy sector and the rest of the economy. Both build projections into the future, called scenarios. The comparison of projections across scenarios creates an impact assessment and policy evaluation conclusions. For both models, projections run to the year 2050. The energy model provides detailed projections under various decarbonization options of energy demand, energy supply, energy prices, investment in energy efficiency for businesses and households, investment in electricity generation, and CO_2 emissions from energy. The macroeconomic model takes selected outputs from the CPS to determine the economy-wide effects of the decarbonization policies. Importantly, the Slovak-CGE model considers the effects of these policies on Slovakia's international competitiveness, crowding-out effects on non-energy investments, and household consumption.

DESIGN OF THE ENERGY MODEL

A country-level energy model provides a bottom-up technology-rich analysis of the key elements of the energy sector. The model captures the European framework for climate and energy policy for 2030 and (proposed for) 2050 so that the impacts of policy decisions on Slovakia can be assessed. The energy model is designed to support energy strategy-making, including assessment of policy instruments, energy demand and supply planning, and evaluation of climate change mitigation policies. The model includes key energy sector metrics at a detailed level: demand for energy by sector and fuel, modelling of energy efficiency possibilities, capacities of technologies, power generation mix, cogeneration and other energy supply technologies, fuel prices and system costs, investment by sector and energy-related CO_2 emissions.

The Compact-PRIMES for Slovakia (CPS) model has been designed to evaluate low carbon options for the energy sector. The energy model is a compact or simplified version of PRIMES which has been constructed for Slovakia but retains the main features of the full PRIMES model. (*Box 2*). The model is a fully-fledged energy demand and supply model designed as a single-country compact tool. It aims at addressing energy system projections, power generation planning, energy price forecasting, CO_2 emissions projections, and energy efficiency policies. The CPS essentially comprises two main modules: one projecting energy supply and the other energy demand (*Figure 10*). As a result, the model can provide estimates of:

(i) energy demand by sector and by energy product driven by activity, income and energy prices;

(ii) energy supply by energy carrier driven by demand and costs;

(iii) energy prices resulting from explicit market equilibrium, and

(iv) investment in demand and supply sectors, driven by costs, technology progress and the dynamic turnover of the energy capital in the various sectors.

Box 2. The Price-Induced Market Equilibrium System (energy) model: PRIMES

The energy model for Slovakia is derived from the well-known PRIMES model

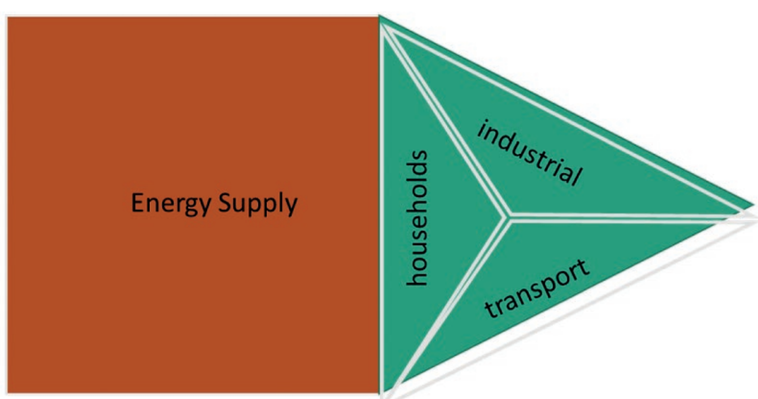
The well-known PRIMES energy model is a partial equilibrium modeling system that simulates the European Union energy system and markets. It provides projections to 2050 of detailed energy balances, both for demand and supply, CO2 emissions, investment in demand and supply, energy technology penetration, prices and costs. The PRIMES model simulates a multi-market equilibrium solution for energy supply and demand and for ETS and other potential markets by explicitly calculating prices which balance demand and supply. PRIMES simulates demand and supply behavior by agent (sector) under different assumptions regarding economic development, emission and other policy constraints, technology change and other drivers.

PRIMES is a hybrid model-- it captures technology and engineering detail together with micro and macro interactions and dynamics. Thus, it integrates technology/engineering details and constraints into economic modelling of behaviors. Microeconomic foundations is a distinguishing feature of the PRIMES model and applies to all sectors. The modelling of decisions draws on economics, but the constraints and possibilities reflect engineering feasibility and restrictions. The model thus combines economics with engineering, ensuring consistency in terms of engineering feasibility, being transparent in terms of system operation and being able to capture features of individual technologies and policies influencing their development. The model performs analytic cost estimations and projections by sector both in demand and supply, as well as for infrastructure. Supply-side modules determine commodity and infrastructure prices by end-use sector (tariffs) by applying various methodologies by sector as appropriate for recovering costs depending on market conditions and regulation where applicable.

Source: E3MLab (2014). PRIMES model 2013-2014: detailed model description. E3MLab/ ICCS at National Technical University of Athens. ec.europa.eu/clima/sites/clima/files/strategies/analysis/models/docs/primes_model_2013-2014_en.pdf.

Figure 10. A simplified diagram of the Compact PRIMES for Slovakia (CPS model)

Modelling Slovakia’s energy sector: supply and demand by sectors are equilibrated

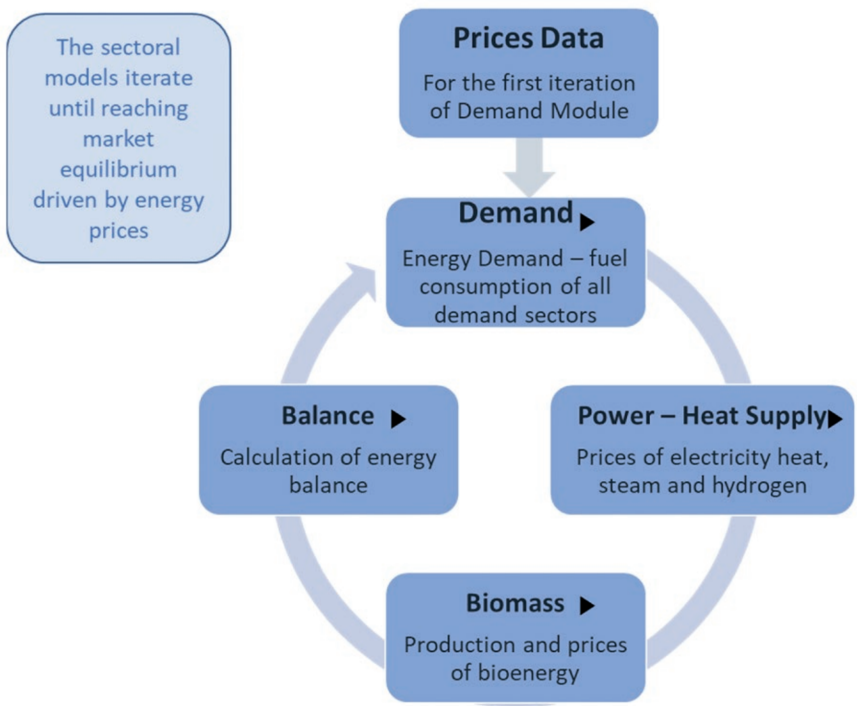


Source: E3-Modelling, CPS Technical Report.

The CPS model is a single-country partial-equilibrium model of the energy sector which balances energy supply and demand. The model uses varying energy prices of commodities to achieve market equilibrium between the demand and supply of energy. The overall CPS model runs sub-models iteratively (*Figure 11)*. The sub-models are representative of sectors, simulating individual actors' decisions in the supply and demand of energy and the balancing of their decisions in simultaneous markets cleared by prices. In this way, the model explicitly projects the energy sector into the future as derived from cost minimization on the supply side and price-elastic behavior of energy demand. The simultaneous market clearing under perfect competition conditions lead to an overall optimum of economic welfare, which coincides with a minimum cost of energy for end-users. In the energy supply sectors, the model performs a detailed breakdown of cost categories, such as capital, operational, emission-related and maintenance costs.

Figure 11. Schematic of operation of the CPS model

The energy model uses energy prices to achieve equilibrium in markets



Source: E3-Modelling, CPS Technical Report.

As a hybrid model with technology and engineering detail together with micro- and macroeconomic interactions and dynamics, the CPS' sectoral decisions consider technology and costs. Each sector (represented in the model by an agent) must choose the amount of energy to use, investments in new equipment and energy savings, and utilization of the equipment. Engineering characteristics are included, as are vintages of capital (to allow a link between the pace of investment and the rate of technological progress). A large variety of technologies, with learning-by-doing dynamics, is in the menu of decision makers in all sectors to select in the choice of new equipment. Generally, the model considers short-term marginal costs to determine the use of existing equipment restricted by the existing stock, and long-term marginal costs to determine the choice of new equipment. Premature replacement of old equipment is also possible depending on relative economic performance. The sectors or sub-models in the CPS model can be seen in *Table 2*. Energy demand includes industry, residential, services, agriculture, and transport. Energy supply includes the power sector, district heating, biomass supply, refineries, gas supply, and the primary production of fossil fuels.

Table 2. Energy demand and supply sectors
The energy model considers detailed demand sectors and energy supply

Demand sectors	Supply sectors
Industry	Electricity and heat supply
Iron and steel	Biomass supply
Non-ferrous metals	Rest of the energy sector
Chemicals	
Building materials	
Paper and pulp	
Food, drink and tobacco	
Engineering	
Textiles	
Other industries	
Non-energy	
Domestic	
Residential (households)	
Tertiary	
Agriculture	
Services	
Transport	
Passenger transport (excluding Aviation)	
Freight transport	
Aviation	

Source: E3-Modelling, CPS Technical Report.

The design of the CPS model aims to capture the essential elements of decision-making related to Slovakia's energy and related sectors. Decisions by the sector agents/firms on use of existing equipment and the choice of new equipment depends on external factors including taxes, subsidies, emission costs and technology standards and on subjective factors including hidden costs, non-market barriers, the opportunity cost of capital funding (discount rates and unit costs of capital) and anticipation of future conditions. Policy instruments and the general enabling conditions that are assumed for a scenario will influence the subjective cost factors while technological progress, policy assumptions, and learning by doing dynamics influence the direct costs. Both the model and the scenario design aim at reflecting true decision-making conditions. The energy supply decisions take into account restrictions regarding the use of resources, such as renewables, domestic fuels, locations and sites to build power and energy plants, sites used for storage of energy or CO_2, biomass feedstock, waste and others. The model represents the limitation of such resources by means of cost-potential curves with ascending slopes, which reflect the increase in unit marginal costs of the resource when approaching the maximum potential.

Key exogenous assumptions drive model results and can be altered as part of different scenarios. The CPS model requires extensive data and information as input assumptions. Macroeconomic drivers are needed, such as GDP, activity by sector, population and income. Fossil fuel prices as well as taxes and subsidies for fuels and equipment must be available. Interest and discount rates are inputted. Fuel and resource availability constraints and cost-potential curves (e.g. renewable potential, domestic reserves for fossil fuels, import limitations, potential of sites for new power plants) as well as economic and technical characteristics of current and future energy technologies (efficiencies, utilization rates, capital, fixed and non-fuel variable costs, learning-by-doing possibilities) are needed. Lastly, the model needs technology standards, emission performance standards, energy efficiency standards as well as emission costs (e.g. CO_2 price in the ETS), energy efficiency targets and renewable targets by sector.

The design of the CPS model is appropriate for the quantification of long-term energy planning and policies reducing energy-related greenhouse gas emissions. The CPS model can provide a variety of important results about the energy sector and energy supply and demand. These outputs include:

(i) Detailed energy balances, final energy demand by sector and process and by energy commodity, distribution losses, energy branch consumption, gross inland consumption primary production and net imports by energy type

(ii) Energy supply by energy carrier and energy prices

(iii) CO_2 emissions by sector and commodity, ETS and non-ETS emission reduction indicators[10]

(iv) Energy saving and energy efficiency indicators

(v) Use of renewable energy sources and RES shares (overall RES share and shares of specific renewable technologies)

(vi) Additional policy indicators (e.g. energy and carbon intensity per sector, import dependency, energy savings, system requirements provision)

(vii) Investments in energy demand management and energy supply by sector and technology

(viii) Costs of the overall system and by sector.

DESIGN OF THE MACROECONOMIC MODEL

A global-level computable general equilibrium model can provide an economy -wide impact analysis of low-carbon policies. CGE models capture the interactions between economic agents (e.g. households, firms, government and external sector) in a simplified way. They are well suited to estimating the long-term effects of policies because they incorporate the supply-side constraints faced by the economy, such as the size of the labor force. A global-level CGE model is able to provide an economy -wide impact analysis of low-carbon policies. CGE models capture the interactions between economic agents (e.g. households, firms, government and the rest of the world) in a simplified way. They use detailed economic data to simulate how an economy might react to changes in policy or other external shocks. Importantly, they are able to capture both the direct and indirect effects of policy reform. (For example, a direct effect of a carbon tax might be the increase

10. The CPS is an energy model, including only CO_2 energy-related emissions. Non-CO_2 (e.g. NOx, F-gases, CH_4) are not taken into account. The CPS includes CO_2 emissions from the combustion of fossil fuels exclusively, while process (or industrial) emissions are not covered. Process emissions, which are due to the chemical transformation of material and not because of fossil fuel combustion, are outside of the model scope.

of production costs in industries using fossil fuels. Then an indirect effect might be a contraction in output caused by the deadweight loss from the tax.) These models focus on the long-term structure of the economy, and they are useful for policy analysis because government policies should be assessed based on their lasting impacts. They provide a consistent framework to analyze the merits of different policy options. Hence, they are a complement to partial equilibrium models, such as the energy market model discussed above.

The Slovakia macroeconomic model has all the features of a standard CGE model. As in any standard CGE model, households maximize well-being subject to income constraints, firms maximize profits subject to available technology, and governments collect revenue from taxation to fund the purchase of goods and services on behalf of households (e.g., in health and education). As in all CGE models, factor and product markets clear through price adjustments. Firms respond to costs when making production decisions, including the amount of energy to use. Higher energy costs encourage investment in more energy-efficient technologies. The interaction between regions (groups of countries) is captured through bilateral trade.

The ENVISAGE-Slovakia applied general equilibrium (Slovak-CGE) model builds on a well-established global model and, like that model, has additional detail in energy, electricity generation, and emissions so that it is useful for the assessment of climate policies. The CGE model developed for Slovakia draws from the ENVISAGE (Environmental Impact and Sustainability Applied General Equilibrium) Version 10 model developed at the World Bank.[11] ENVISAGE is a global dynamic computable general equilibrium model designed specifically to analyze the economy-wide impacts of climate policies. It is designed to analyze a variety of issues related to the economics of climate change, including emissions of CO_2 and other greenhouse gases (methane, nitrous oxide and fluoridated gases), impact of mitigation policies on the economy, and some distributional consequences of mitigation policies. The macroeconomic model for Slovakia is named the ENVISAGE-Slovakia applied general equilibrium (Slovak-CGE) model (*Figure 12*).

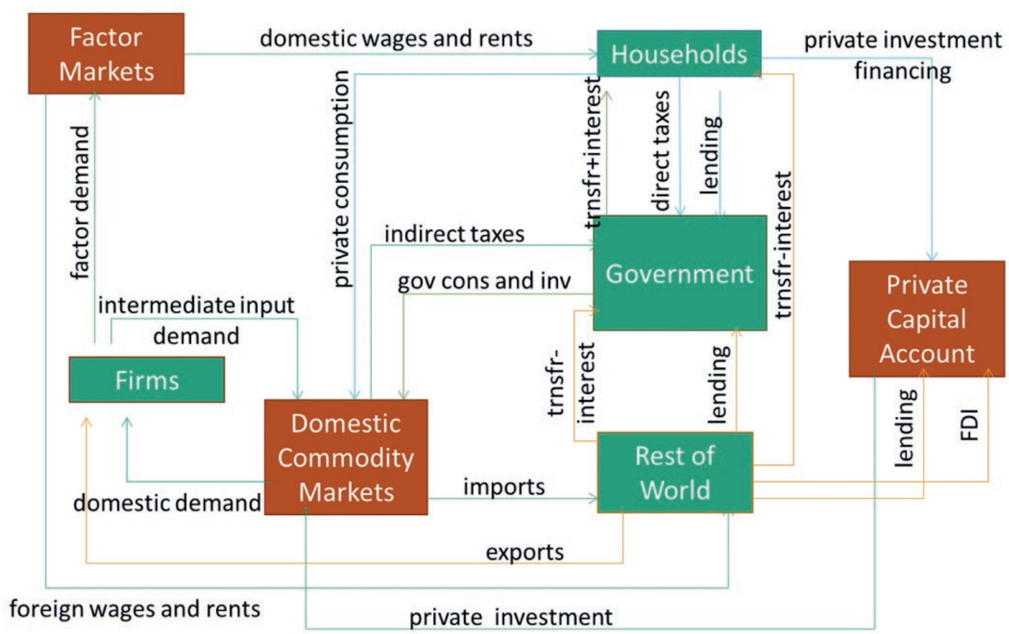
In each sector in the Slovak-CGE model, a representative firm chooses the level of each factor input to produce its output, subject to its production technology. The factor inputs distinguished in the Slovak-CGE model are: skilled workers, unskilled workers, capital, land, and natural resources, plus intermediate inputs, including energy commodities and other goods and services. The production technology is a nested constant elasticity of substitution (CES). The CES technology captures the substitutability between factors of production. The decision by firms on which factors to use depends on relative factor prices: for example, an increase in wages would lead to substitution away from labor, towards capital. Importantly, the model captures the variations in technology across industries. That is, some industries find it easier to substitute between factors of production compared to others. For example, manufacturing firms may find it easier to substitute between labor and capital, whereas services firms may find this more difficult.

The Slovak-CGE model has been customized to reflect the particular features of the Slovak economy. The model identifies 39 industries, including heavy manufactures such as iron & steel manufacturing. The 39 industries produce 31 commodities, and aggregate economic outcomes such as GDP are derived by adding up industry/commodity level outcomes. The model operates at a global scale, separately identifying four regions: Slovakia, other Visegrad group countries (the Czech Republic, Hungary and Poland), other EU countries and the rest of the world. Slovakia's exports to and imports from the other three regions are detailed by commodity, and they adjust in response to price changes. The model simulates a baseline

11. Van der Mensbrugghe, Dominique (2008). The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model. Processed, The World Bank.

scenario and alternative policy scenarios including different structural and climate policies for Slovakia. The model shows how energy in various forms is used as inputs to production (by industry) and consumption, and therefore how it adds to production or consumption costs. The CGE model provides comprehensive long-term projections of key economic indicators through 2050. The CGE model accounts for economywide effects of policy shocks, including industry outputs, commodity prices, exports and imports, investment and household consumption, government revenues from different types of taxes, and employment and wages.

Figure 12. Simplified diagram of the ENVISAGE-Slovakia Applied General Equilibrium (Slovak-CGE) Model
A macroeconomic model captures impacts across the economy



Source: World Bank, Slovak-CGE model documentation.

In Slovak-ENVISAGE, demand for energy commodities across households and firms is price sensitive, and various electricity generation options are captured. The energy commodities in the model include: coal, oil, petroleum, gas and electricity. Also, the model identifies several methods of generating electricity: nuclear, coal, gas, oil, wind, hydro, solar and other renewables. (Importantly, during the development of Slovak-ENVISAGE, the power generation block was harmonized with power generation in the energy model.) In the CGE model, a representative firm in each industry is able to determine the amount of each energy commodity used in their production, and this decision depends on prices. The choice of electricity generation technology for the electricity supplier is also price sensitive. Climate change policies which increase the cost of traditional generation technologies would lead to substitution away from these technologies, e.g. substitution away from coal-powered generation to wind power.

Emissions are explicitly modeled. The greenhouse gases captured in the model include: carbon, methane, nitrous oxides and fluoridated gases. Slovak-ENVISAGE accounts for emissions that are generated by the consumption of fuels, agricultural production and livestock, and industrial process emissions. The power and emissions module allows the model to estimate the effects of government policies on the energy and emissions intensity of the economy.

Note that the split between ETS and non-ETS in the Slovak-CGE model is simplified. Since the model does not include installation level detail, the assignment to either ETS or non-ETS was based on industry rather than installation characteristics. The following energy-intensive industries in the Slovak-CGE model where assigned to the ETS sector: power and heat generation; paper and pulp; petroleum and coke; iron and steel; non-ferrous metals; chemicals, rubber and plastic; non-metallic minerals; additional industries, based on the assumption that most of their emissions are covered by the ETS: mining, food, beverage and tobacco, fabricated metal products, motor vehicles production, other transport equipment, air transport (apart from CO_2, the ETS also covers emissions of fluoridated gases from aluminum production, and nitrous oxide emissions from chemical production). Emissions from the remaining industries and households were assigned to non-ETS.

Dynamics in the model are recursive. They are driven by population growth, technological change and capital accumulation. Population growth is an exogenous input into the model, using population scenarios from the International Institute for Applied Systems Analysis (IIASA), which is part of their Shared Socio-economic Pathways database. The pace of technological change across industries is also exogenous to the model. The accumulation of capital is endogenous to the model and follows a stock-flow adjustment process: each year, investment adds to the existing capital stock after allowing for depreciation.

The Slovak-CGE model can analyze a variety of mitigation policies on its own. The model's detailed treatment of energy and emissions makes it capable of use as a stand-alone tool for the assessment of climate policies. The Slovak- CGE model is capable of analyzing mitigation policies, such as carbon taxes, cap and trade systems at the regional or national level, energy efficiency investments; and regulation of the electricity generation mix (e.g., a renewable energy target). The model then estimates effects of these policies on key economic indicators such as: GDP, consumption, investment, trade, sectoral output and employment, as well as GHG emissions. For example, the Slovak-CGE model can estimate the impact of an increasing ETS CO_2 price across the Slovak economy as well as on other countries (other Visegrad countries, the rest of the EU, and the rest of the world).

USING THE ENERGY AND MACROECONOMIC MODELS TOGETHER

The CPS is a fully-fledged energy model. It provides detailed projections of energy demand, supply, prices and investment to the future, covering the entire energy system including CO_2 emissions. The CPS captures the main channels for answering energy, transport, and industry questions such as:

(i) What is the size and type of investments required to move to low carbon electricity production? What are the implication of such policies for electricity prices?

(ii) What actions can achieve energy efficiency improvements in households? At what cost? What is the level of renovation required to reach a certain level of emission reduction in the non-ETS sector?

(iii) How does the passenger transport fleet need to evolve to meet requirements in the non-ETS sector? At what cost? Which policies are needed?

(iv) What actions may be taken by the industrial sector to reduce fuel consumption? What is the level of savings that may be achieved by each sub-sector? (*Figure 13*).

By comparison, the aim of the Slovak-CGE model is to simulate the economic effects of moving towards a low carbon economy. It captures the main channels for answering the following questions:

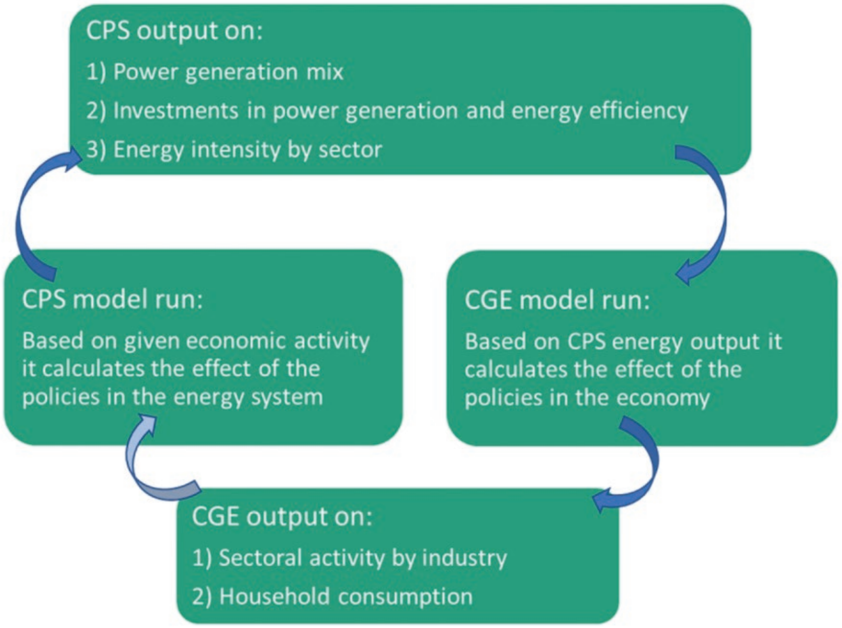
(i) What is the opportunity cost of investing in "greener" technologies compared with other investment opportunities ("crowding out")?

(ii) Which sectors in the economy are stimulated by this "green" investment (construction, agriculture, manufacturing of equipment)?

(iii) What are the effects of electricity/energy price changes on output prices and demand (including foreign demand)? (*Figure 13*).

The CPS and Slovak-CGE models together allow for a richer assessment of policies, with each contributing accuracy and details based on their design. The CPS model's detailed projections of energy demand and supply are used as inputs to the Slovak-CGE model's simulations of the Slovak economy's performance. The assessment of policies is strengthened when the detailed energy system results from the CPS model are as an input to the Slovak-CGE model which, in turn, assesses the economywide impact of the same climate policies. It is important to note that the Slovak-CGE model uses its own energy outputs to assess outcomes for the other three regions but uses the detailed CPS results for Slovakia. Also, the linking modes between the models are different for the reference (or baseline) scenario and the decarbonization (or policy) scenarios. Between the two models, the key elements of a low carbon growth path can be carefully probed, and policy options compared and assessed.

Figure 13. Basic links and order of model operation between the CPS and Slovak-CGE models
Linking the CPS and Slovak-CGE models allows a richer assessment of policies



Note: The link from Slovak-CGE output to the CPS model run will be used if iterations of the models are needed to converge on similar levels of economic activity.

Source: World Bank staff.

KEY DATA SOURCES AND EXOGENOUS ASSUMPTIONS

The CPS model draws on multiple data sources and builds on the information used by the EU for constructing scenarios. The CPS model draws on data from Eurostat, IEA, power plant databases (such as from Platts), and the PRIMES model, supplemented and updated by the Slovak authorities. The model is calibrated using Eurostat data to 2015, and the short-term projection to 2020 reflects information on likely trends provided by the Slovak authorities. The main input data of the CPS model are as follows:

(i) Macroeconomic variables such as GDP, activity by sector, population, and income

(ii) Fossil fuel prices, taxes and subsidies for fuels and equipment

(iii) Interest and discount rates[12]

(iv) Fuel and resource availability constraints and cost-potential curves (e.g., renewable potential, domestic reserves for fossil fuels, import limitations, potential of sites for new power plants)

(v) Techno-economic characteristics of current and future energy technologies (efficiencies, utilization rates, capital, fixed and non-fuel variable costs, learning-by-doing possibilities)

(vi) Technology standards, emission performance standards, energy efficiency standards

(vii) Emission costs (the price of CO_2 in the Emission Trading System of the EU), energy efficiency targets, and renewable targets by sector.

(viii) Eurostat data (to calibrate the model's outputs to the base year of 2015).

The Slovak-CGE model depends on a key global database and World Bank data. The model is built on a database of economic information for over 140 countries developed and maintained by the Center for Global Trade Analysis (GTAP). GTAP is a consistent global database of input-output tables that is widely used for global CGE modelling.

The Slovak- CGE and CPS models share the same exogenous assumptions for the following variables:

(i) Population projections for Slovakia;[13]
(ii) In the Slovakia reference scenario, GDP projections for Slovakia, from the 2016 EU reference scenario; [14]

(iii) Fuel price projections. World fossil fuel prices are taken from the projections used in the EU reference scenario. Oil prices are projected to rise more quickly than natural gas or coal prices due to persistent global demand growth in developing regions (*Figure 14*).

(iv) Price of ETS CO_2 emission allowances.

12. Based on discussions with the government, the financing cost of nuclear power is assumed to be the same as other power technologies—8.5 percent.

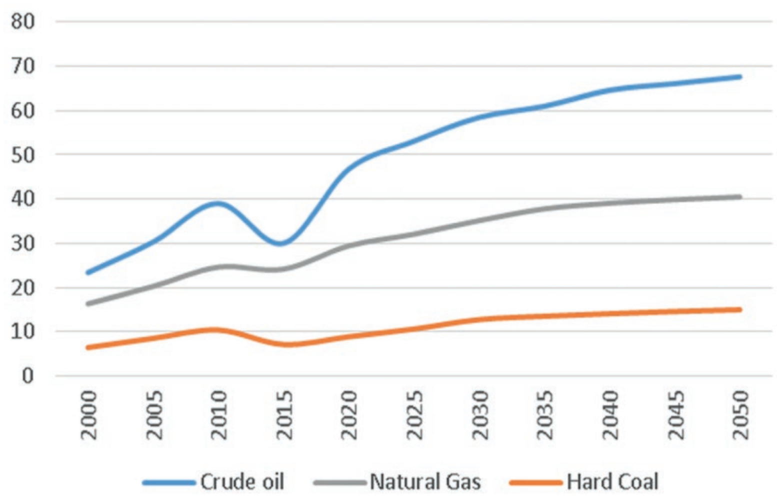
13. See Chapter 3 Section 2 for a discussion. From European Commission (2014), The 2015 Ageing Report: Underlying Assumptions and Projection Methodologies. European Economy 8/2014. Directorate-General for Economic and Financial Affairs (DG ECFIN). ec.europa.eu/economy_finance/publications/european_economy/ageing_report/index_en.htm.

14. Capros, P., De Vita, A., Paroussos, L., *et. al.* 2016. EU Reference Scenario 2016. Luxembourg: European Commission. ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf..

In addition, the Slovak-CGE model takes the CPS' projections for energy use by sector and electricity generation mix as inputs. The CPS models the energy sector in greater detail than the CGE model, whereas the Slovak-CGE model has a better representation of the links between the energy sector and the wider economy.

Figure 14. Projection of world fossil fuel prices, €/MWh in equivalent NCV

Oil prices are projected to rise faster over the long-term than other fuel prices



Notes: Projections from E3-Modelling's Prometheus world energy system model. NCV is net calorific value, a measure of the energy content of each fuel.

Source: E3-Modelling, CPS Technical Report.

Other exogenous inputs into the Slovak-CGE model are listed below and are used mainly for the projections for the other regions specified in the model (Visegrad countries, rest of the EU and rest of the world). These projections were sourced from the World Bank's annual Macro Poverty Outlook data, the World Bank's population projections, and the EU's Ageing Report:

(i) Population projection for regions/country groupings other than Slovakia

(ii) Labor force participation rates

(iii) GDP projections for the regions/country groupings other than Slovakia

(iv) Investment as a percent of GDP

(v) Government consumption as a percent of GDP

(vi) Government budget balance as a percent of GDP.

CHAPTER 3

"BUSINESS AS USUAL" FOR SLOVAKIA'S ECONOMY

A business-as-usual projection for Slovakia that includes national obligations on climate action through 2020 is set up as the reference scenario, against which other scenarios can be compared. This scenario builds on the 2016 EU Reference Scenario. The Slovakia reference scenario assumes that there are no further supporting climate policies post-2020 other than the ETS, but that energy efficiency improvements are sustained. GDP growth is expected to slow to 0.6 per cent per annum by 2050 in Slovakia, driven by a fall in population. Within the overall story of slowing growth, some sectors and subsectors continue to expand while others contract. For example, the projected rise in per capita incomes supports an expansion of the services sector. The Reference Scenario projects continuous energy efficiency improvements. The ETS will continue as a key influence on energy choices through 2050 in the Reference scenario. Energy demand in industry will continue to moderate in the Reference Scenario as new efficient technologies are embedded in productive investment in industry. ETS prices in the reference scenario push industrial energy consumption towards less carbon-intensive fuels. Demand for electricity rises through the projection period. Nuclear energy plays a crucial role in the electricity mix of Slovak Republic, but wind and solar do not expand substantially under the reference scenario. Power sector investment shifts over time in the reference scenario, from nuclear to CCGT to solar. Without supporting policies after 2020, the ETS price is not sufficient to drive significant reductions in emissions.

DEFINITION OF THE REFERENCE SCENARIO

A baseline or reference scenario is a starting point to understand policy options. The reference scenario for Slovakia is a business-as-usual projection including national obligations on climate action only until 2020. This scenario is similar to the EU Reference Scenario constructed for the European Union in 2016. It includes the policies adopted and implemented until a cut-off date (2017) and additional policies as needed to achieve the renewables and efficiency obligations of the country in 2020.[15] The trajectory of prices for ETS allowances draws on the projection of ETS prices for the EU Reference Scenario 2016 (*Box 3*).

Box 3. The European Union's Reference Scenario 2016

The European Union's assessment of climate policies started from a common baseline scenario

To accompany the 'Winter Package', the European Commission supported creation of a reference or baseline scenario for the European Union through 2050 to form the basis for comparison to the Winter Package measures. The EU Reference Scenario provided a projection of all 28 EU member states' energy system, transport sector, and greenhouse gas emissions through 2050 to act as a benchmark to inform policy making. It assumed that GHG and renewables targets for 2020 would be achieved and that current policies (through early 2015) would be continued. The modeling used Eurostat data, the "2015 Ageing Report" for long-term population and GDP growth trends, and shorter term growth projections from DG ECFIN. The modeling was undertaken with a suite of interlinked economic and engineering models, including PRIMES

Source: Capros, P., De Vita, A., Paroussos, L., et. al. 2016. EU Reference Scenario 2016. Luxembourg: European Commission. ec.europa.eu/energy/sites/ener/files/documents/ref2016_report_final-web.pdf.

The Slovakia reference scenario assumes that there are no further supporting climate policies post 2020, other than the ETS. The reference scenario is broadly in line with the results of EU Reference Scenario 2016 for Slovakia, including exogenous assumptions such as GDP and the ETS price. The evolution of energy demand and supply depends on market forces and market-driven technological progress. In other words, there is no new policy, beyond 2020, with the notable exception of the ETS, which operates subject to the Market Stability Reserve mechanism until 2050. The steadily increasing CO_2 prices significantly influence the ETS sectors: power generation, heat supply and energy-intensive industry, until 2050. The evolution of ETS prices imply considerable emissions reduction in these sectors in the entire period after 2020. However, the non-ETS sectors do not have new policies after 2020. (*Figure 25*).

Energy efficiency improvements are sustained in the reference scenario. Despite the lack of new policies beyond 2020, the reference scenario is not a frozen efficiency projection. Energy efficiency improvements in all sectors continue in the future, albeit at a slower pace than if new policies were enacted. The EU energy efficiency directives already implemented and eco-design regulations for domestic appliances, motors and other electric equipment will have rising impact. Most importantly, the drivers of efficiency progress are market forces. In industry, energy efficiency progress is part of the quest for productivity growth, which is part of a sustained growth of value added. In the buildings and transport sectors, energy efficiency improvement is due to the commercialization of increasingly efficient equipment and vehicles as the industry

15 The scenario also includes some EU Directive amendments, such as the ILUC to the Renewables Directive and Fuel Quality Directive and the Market Stability Reserve Decision to the ETS Directive.

considers the reduction of operation costs as a marketing factor able to increase in sales. Therefore, the decoupling of energy consumption from economic growth continues in the future as a result of technological progress (incorporated in the values of the corresponding parameters of the model chosen to reflect market forces, set below the values that would be reasonable for policy-related technology progress).

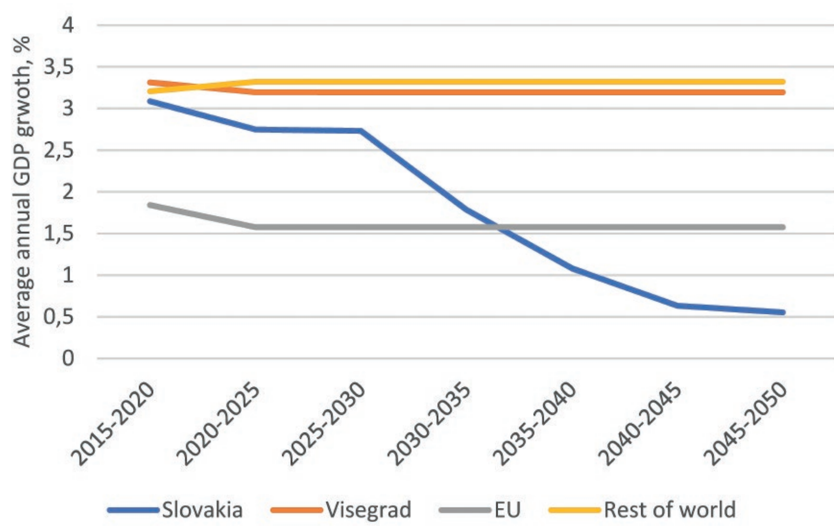
Both the energy and the macroeconomic model start from a reference scenario aligned with the EU scenario. For the reference scenario, the CPS and Slovak-CGE models share the same external assumptions based on the EU Reference 2016 scenario concerning GDP growth, fossil fuel prices and, broadly, the production structure. The Slovak-CGE model is not used to generate baseline projections for macroeconomic variables. Rather, both models are calibrated to a common macroeconomic projection provided externally. However, baseline results for energy variables from the CPS model are incorporated into the Slovak-CGE baseline solutions.

MAIN CHARACTERISTICS OF THE REFERENCE SCENARIO

GDP growth is expected to slow to 0.6 per cent per annum by 2050 in Slovakia, driven by a fall in population. This growth path, from the EU Reference Scenario 2016, can be compared to those for the other regions in the model (Visegrad countries, rest of the EU, and rest of the world), from the exogenous sources listed previously (*Figure 15*). Slovakia's overall economic growth rate drops after 2030, falling below averages in the rest of the world. However, continued gains in productivity support Slovakia's GDP growth in per capita terms. Solid income growth leads to higher levels of consumption with consumption becoming a more important component of GDP over time. Investment is expected to be maintained at historical levels at around 23 per cent of GDP (based on constant-price shares). Exports continue to be important to the Slovak economy: exports of goods and services are around 90 per cent of GDP over the projection period (based on constant-price shares). Overall, the current account surplus is expected to narrow, driven by increased imports. (*Figure 16* and *Table 3)*.

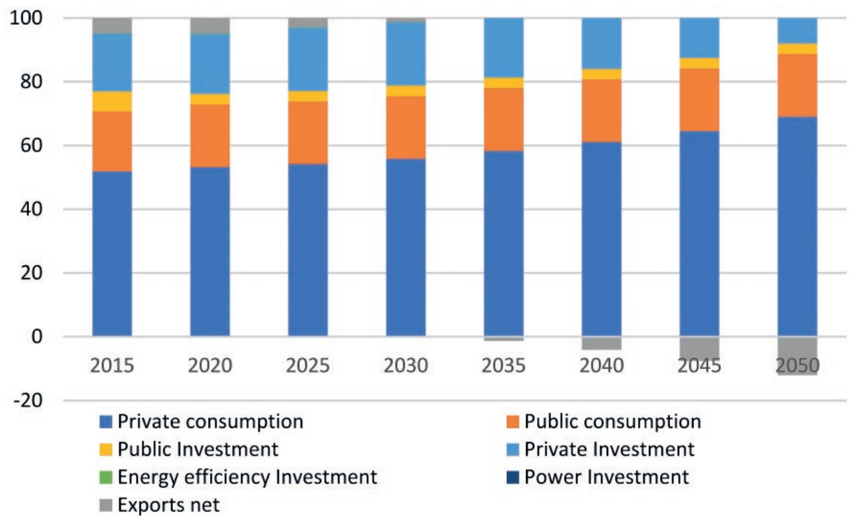
Figure 15. Annual growth rates in Slovakia and the other three regions in the Slovak-CGE model, 2015-2050, real GDP growth in %

Slovakia's modest growth rate is projected to drop below its neighbors after 2030



Source: EU Reference Scenario 2016; World Bank Macro Poverty Outlook.

Figure 16. Shares of real GDP by expenditure, reference scenario, 2015 to 2050, in %
Consumption is projected to rise as a share of overall income in the reference scenario



Note: Shares were calculated based on expenditure components in constant prices.
Source: Slovak-CGE model results.

Within the overall story of slowing growth, some sectors and subsectors continue to expand while others contract. Selected export-oriented subsectors within manufacturing, such as the motor vehicle subsector (within Engineering in Table 3), undergo continued expansion, driven by external demand. Other sectors drive the slowdown. The chemicals sector is affected by strong competition from non-EU countries such as China, India and the USA and records among the lowest sector growth rates. For the textiles sector, the projected decline also comes as a result of international competition (*Table 3*).

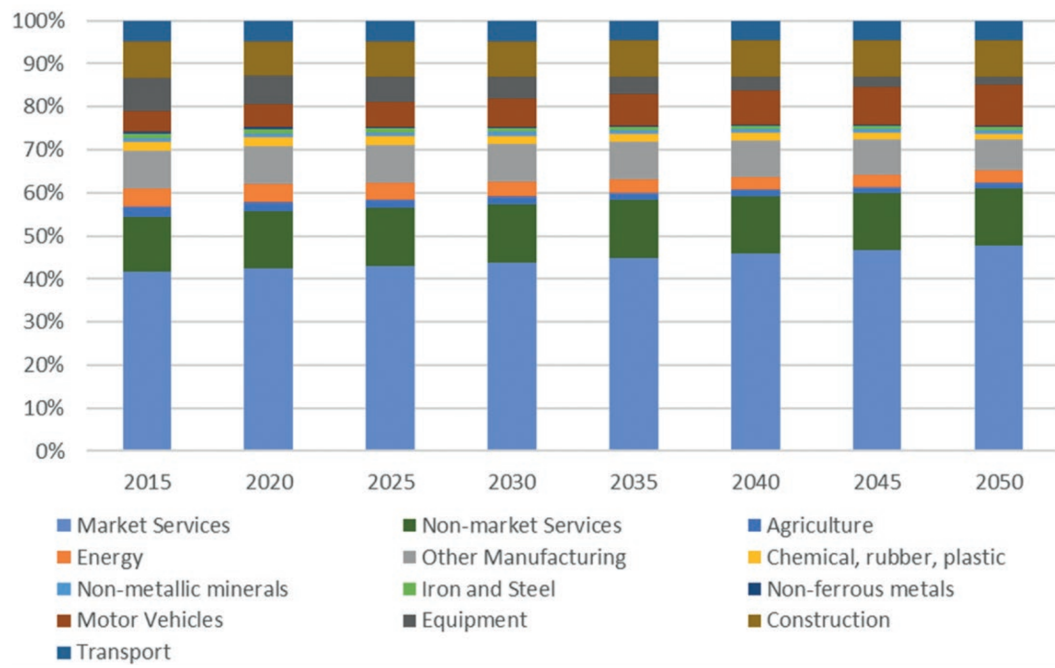
Table 3. Average annual growth rates of GDP and sector value-added, reference scenario, 2020 to 2050, in % per annum
Despite slowing overall growth, selected manufactures and services expand in the reference scenario

Average annual growth rate (% p.a.)	2020	2025	2030	2035	2040	2045	2050
GDP	3.1	2.7	2.7	1.8	1.1	0.6	0.6
Iron & Steel	1.7	1.2	0.9	0.6	0.2	-0.5	-0.7
Non Ferrous	2.1	1.4	1.1	0.9	0.2	-0.4	-0.5
Chemicals	1.8	1.5	1.6	0.9	0.5	0.2	0.1
Building Materials	2.5	2.4	2.5	1.2	0.5	0.2	0.1
Paper & Pulp	2.0	2.1	2.0	1.3	0.7	0.3	0.2
Food, Drink, Tabacco	2.4	2.2	2.1	1.4	0.7	0.1	-0.1
Engineering	3.0	2.5	2.7	1.9	1.0	0.8	0.8
Textiles	-0.1	-0.1	0.0	-0.7	-1.1	-1.5	-1.5
Other Industries	2.0	1.8	2.1	1.1	0.4	-0.3	-0.4
Services	3.3	2.9	2.9	1.9	1.3	0.8	0.7
Agriculture	1.8	1.4	1.8	0.8	0.2	-0.5	-0.6

Source: EU Reference Scenario 2016.

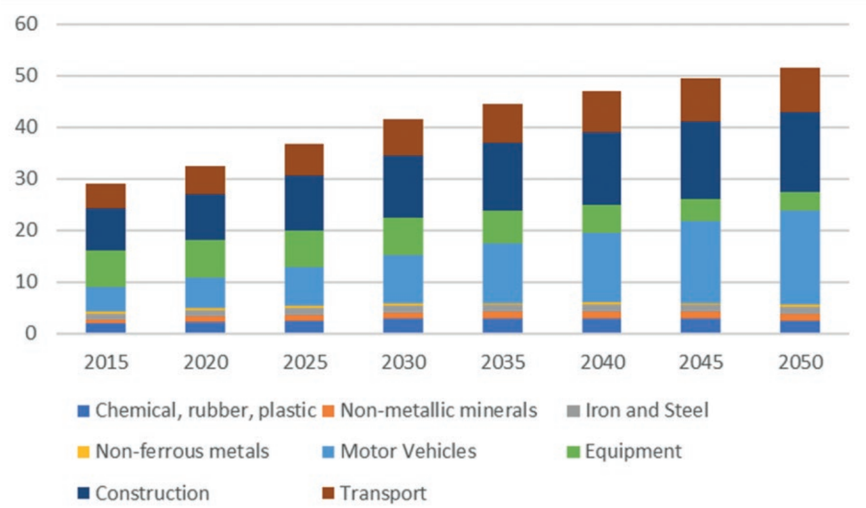
This rise in per capita incomes supports an expansion of the services sector. Market services, which includes business and personal services, expand to about 48 per cent of the economy by 2050 (based on constant-price shares, from about 42 percent in 2015). Export-oriented sectors, such as motor vehicle manufacturing, also continue to expand, driven by continued investments in the sector and external demand. Other heavy manufactures, such as iron and steel, non-ferrous metals (mainly aluminum), and chemicals, contract as a share of the economy over time due to strong competition from emerging markets (*Figure 17* and *Figure 18*).

Figure 17. Share of value-added by sector, reference scenario, 2015 to 2050
Services expand as per capita incomes rise in the reference scenario



Source: Slovak-CGE model results.

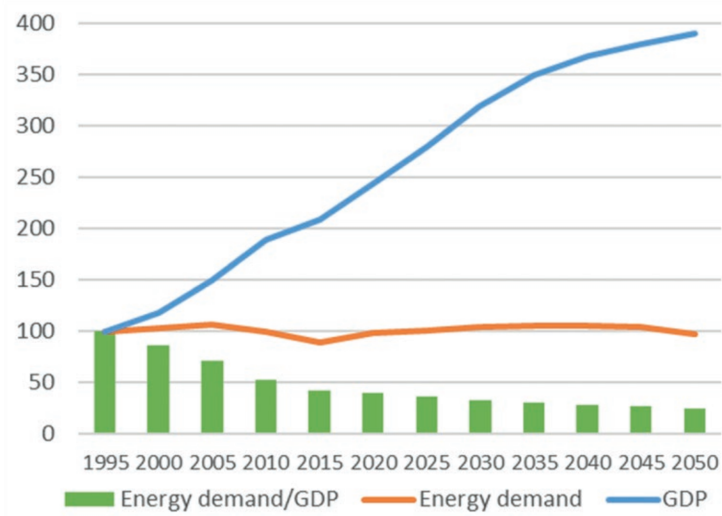
Figure 18. Share of value-added by industrial subsector, reference scenario, 2015 to 2050
Export-oriented subsectors such as motor vehicles are expected to expand while heavy manufactures recede from foreign competition in the reference scenario



Source: EU Reference Scenario 2016.

The reference scenario projects continuous energy efficiency improvements. These improvements are faster than historical trends until 2020 due to the assumed efficiency policies, but they slow down after 2020. The energy efficiency improvements move at a slow pace beyond 2020 due to the absence of new efficiency-promoting policies. However, the energy intensity of GDP, measured by the ratio of gross inland energy consumption over GDP, declines over the entire projection period, thus continuing past trends of a decoupling of energy demand from economic growth. The decline of energy consumption in industry has been the most striking component of this improvement to date, as energy efficient technologies embedded in productive investment have taken hold and as production has shifted away from energy-intensive subsectors and production processes. The ongoing penetration of renewables in power generation and the construction of efficient combined cycle gas plants both help the acceleration of the energy efficiency decline measured at the level of primary energy, as the energy efficiency of power generation increases in future years. The adoption of efficiency-promoting standards for vehicles, eco-design regulations, the impressive technological progress in lighting, and the renovation of buildings are among the factors that have helped in the past and will sustain energy efficiency improvement of the Slovak economy (*Figure 19*)

Figure 19. Energy demand, energy intensity, and GDP, in the reference scenario, 1995-2050, index
Energy efficiency improvements continue although with a slowing pace in the reference scenario



Notes: Energy demand is gross inland consumption; energy intensity is the ratio of gross inland consumption to GDP.
Source: E3-Modelling, CPS Technical Report.

The ETS will continue as a key influence on energy choices through 2050 in the reference scenario. A case of notable long-term impact on power generation and on industry is the Emission Trading System including the Market Stability Reserve Decision. The latter implies that the ETS carbon prices are likely to increase in the Reference scenario continuously, starting from 2020 until 2050. The significant removal of allowances from the market, as part of the mechanism, implies anticipation of scarcity of allowances in the future due to the expected strong decrease in the surplus of allowances that is currently persisting in the ETS market. Because of such expectations, the ETS market players are likely to increase banking of allowances to avoid future exposure to high prices. Because the mechanism provisions remove from the market higher amounts of allowances than the amounts returned to the market from the reserve, it is likely to see a continuous reduction of the surplus despite a possible increase in the banking. This sustains anticipations about scarcity on the future and thus supports the conjecture that the carbon prices are likely to increase in the future continuously. The ETS provisions last until 2050, when an ultimate reserve has to remain, which also add to the argument that the ETS prices are likely to increase in the long-term. The effects of the rising ETS carbon prices on the fuel mix in industry and in the power and heat sectors are considerable (*Table 4*)

Table 4. Key policy indicators in the reference scenario
Energy emissions fall, especially in the ETS sectors, but renewables falter in the reference scenario

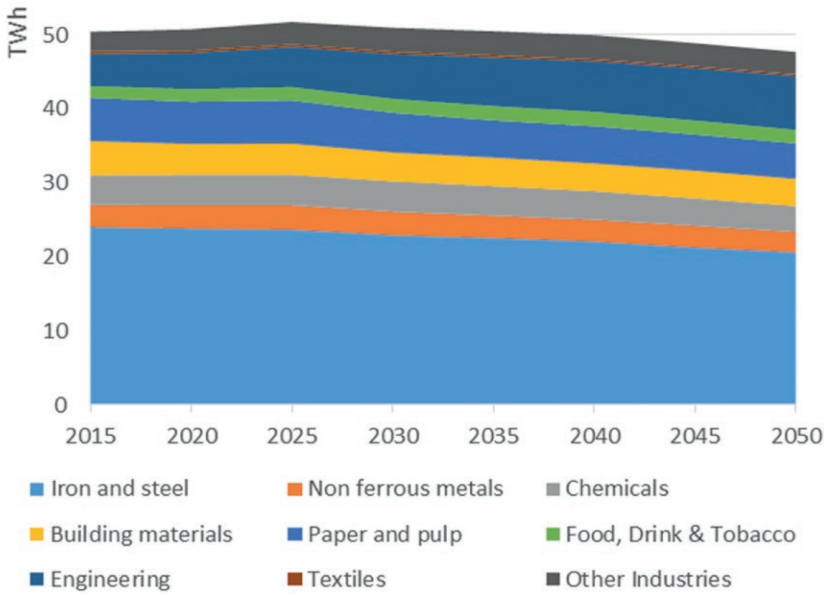
	2015	2020	2025	2030	2035	2040	2045	2050
GHG emissions (% change from 1990)	-44.7	-43.7	-43.3	-41.4	-42.1	-43.3	-45.2	-45.6
CO_2 emissions (% change from 2005)	-27.3	-27.8	-28.9	-27.8	-29.9	-31.8	-34.6	-34.9
ETS sectors	-30.8	-34.9	-38.0	-38.4	-43.0	-44.8	-47.3	-47.3
non-ETS sectors	-21.4	-15.7	-13.6	-9.9	-7.6	-9.9	-13.0	-14.1
Overall RES share (%)	14.0	14.5	15.0	14.3	15.1	15.4	15.8	18.3
RES-H&C share	14.2	13.3	15.0	14.0	15.5	16.0	16.5	17.7
RES-E share	19.4	23.4	21.8	21.3	21.7	21.7	21.9	28.5
RES-T share	8.3	10.1	10.2	10.2	10.6	11.0	11.5	13.2
Primary energy savings (%)	0.0	-20.2	-23.7	-24.9	0.0	0.0	0.0	0.0

Notes: CO_2 emissions are from energy combustion only. Primary energy savings is compared to PRIMES 2007 baseline projection. H&C is heating and cooling; RES-E is renewable energy in the energy sector; RES-T is renewable energy in the transport sector.
Source: E3-Modelling, CPS Technical Report.

Energy demand in industry will continue to moderate in the reference scenario as new efficient technologies are embedded in productive investment in industry. Over the last decade, economic recovery has implied new production investment in industry, which brought additional energy efficiency progress through new technologies embedded in investment. The projections show a continuation of these trends on the coupling of the industrial investment cycles and the energy efficiency progress. Market forces are the drivers, notably the quest for high productivity growth as a factor in industrial competitiveness. The two main drivers influencing this projection are the energy efficiency embedded in the new capital vintages, replacing the existing and old equipment stock, along with the structural changes in the activity, which is assumed to shift towards higher value added and less energy-intensive production processes. The reference scenario assumes that energy-intensive industrial production will remain in Slovakia and will restructure towards higher competitiveness based on specialized high value-added production. Textiles will display a declining trend due to international competition (e.g. China). Other less energy intensive industries will remain and grow more than average in Slovakia either due to domestic demand (e.g. food industry) or due to the European market and the specialty of Slovakian economy (e.g. equipment goods industry) (*Figure 20*).

ETS prices in the reference scenario push industrial energy consumption towards less carbon-intensive fuels. The ETS prices encourage a significant shift of energy consumption of industrial sectors towards less carbon intensive fuels throughout the projection period. The consumption of solid and liquid fuels (petroleum fuels) declines by 28 percent and 38 percent respectively in 2050 compared to 2015 levels. The efficiency improvements are consistent with the adoption of best available techniques promoted by the Integrated Pollution Prevention and Control and the Industrial Emission (IED) Directives. The rising ETS prices and other factors, such as convenience and technological progress, favor electrification in industry, which trends upwards in the reference scenario so that electricity covers almost one-third of total energy demand in industry by 2050. The use of gas is stable, both by quantity and by market share. The use of biomass and waste increases in the short term and remains stable in the long-term, as the ETS prices favor their use while supply limitations and costs limit them.

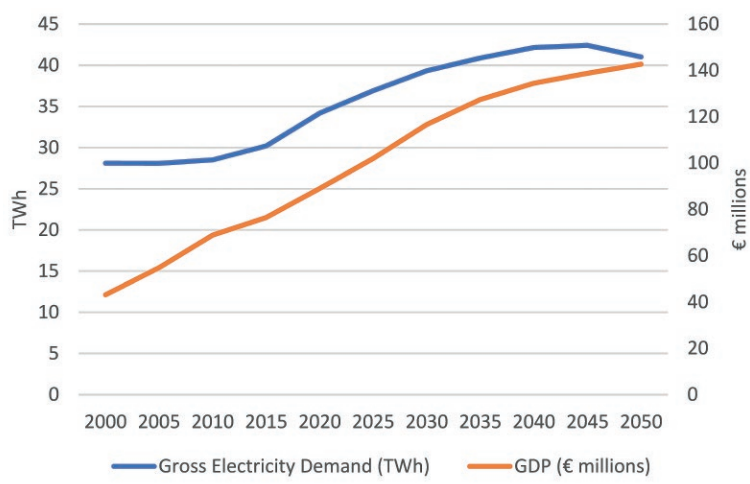
Figure 20. Energy demand by sector, reference scenario, 2015 to 2050, TWh
Iron and steel continue to dominate industrial sector energy demand in the reference scenario



Source: E3-Modelling, CPS Technical Report.

Demand for electricity rises through the projection period. Gross electricity demand includes electricity consumption in all final demand sectors (industry, residential, tertiary, transport), grid losses, exports of electricity and consumption in the energy sector (by refineries and as part of primary extraction of fuels). Electricity supply comprises generation from thermal, nuclear, hydro, and renewables plants and electricity imports. The use of electricity in the various demand sectors shows an ascending trend. Thus, total gross demand for electricity is projected to grow faster than other forms of energy; however, it is projected to expand below the growth rate of GDP. While electricity demand rises by more than one-third between 2015 and 2050, GDP rises far more, so that energy intensity of output (measured as TWh of electricity demanded per € of output) by about one-quarter during 2015-2050, after dropping by about 40 percent during 2000-2015 (*Figure 21)*.

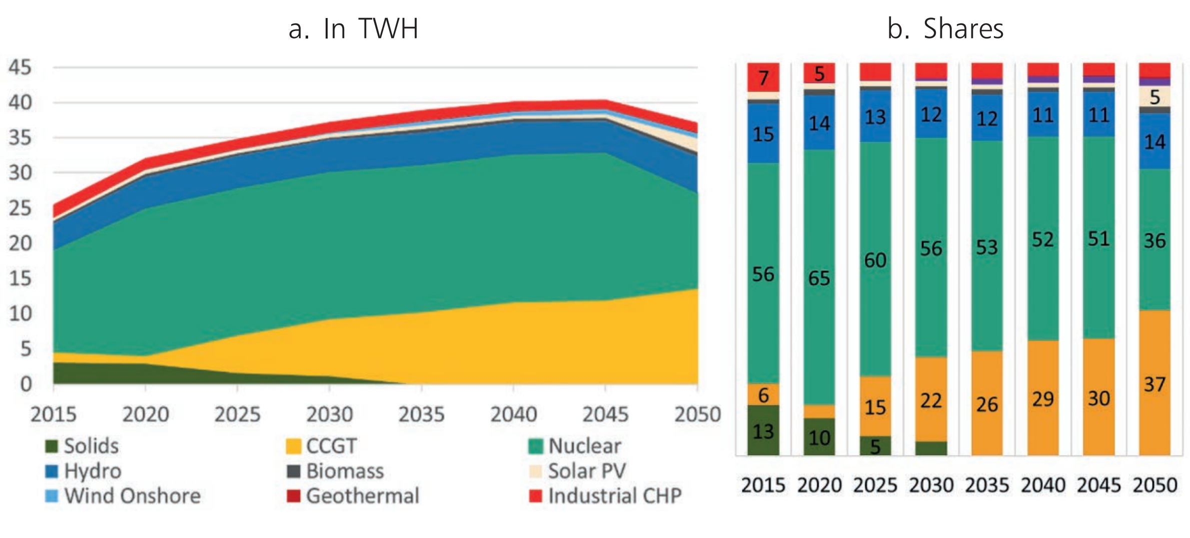
Figure 21. Gross electricity demand, reference scenario, 2000 to 2050, in TWh and real GDP in € millions
Demand for electricity in the reference scenario shows a steady climb



Notes: Real GDP in 2015 euros.
Source: E3-Modelling, CPS Technical Report.

Nuclear energy plays a crucial role in the electricity mix of Slovak Republic, but wind and solar do not expand substantially under the reference scenario. The projection of electricity and heat production into the future depends on demand, the fuel price projection, the ETS carbon prices, the resources of renewables and domestically produced fuels such as lignite and their costs, technology costs, and policy constraints. The policy constraints regard possible limitations on expansion or use of power generation resources. In 2015, nuclear generation covered 56 percent of total net electricity generation. The reference scenario projects an increase in the nuclear share in the medium term (2020 – 2025) due to the commissioning of two new nuclear reactors at Mochovce. Thus, nuclear generation remains stable in volume terms, as the scenario also assumes an extension of the lifetime of old Bohunice reactors until 2045. The decommissioning of old Bohunice reactors after that date and the policy assumption that no new reactors can be added to Bohunice push down the share of nuclear generation in the long-term to 36 percent. At the same time, the use of solid fuels for power generation declines rapidly, as rising ETS prices erode coal's competitiveness. Hydropower remains relatively stable over time, while wind and solar remain marginal. Gas plants ensure the balancing and reserves in the system and fill the energy gap left after the phase-out of solid-fuel plants and the non-expansion of nuclear energy after 2020. Therefore, the power generation by CCGT plants increase significantly in the medium and long term. The development of wind turbines and solar photovoltaic (PV) is modest in the Reference scenario until after 2040 despite the rising ETS prices and the projected decrease of unit capital costs of these technologies. The scenario assumes no support to variable renewables beyond 2020 and Slovakia has limited wind and solar potential, especially regarding the intensity of the resources expressed by relatively low capacity factors. Therefore, the projection shows a share of only seven percent of variable renewables in the power mix of 2050 (*Figure 22*).

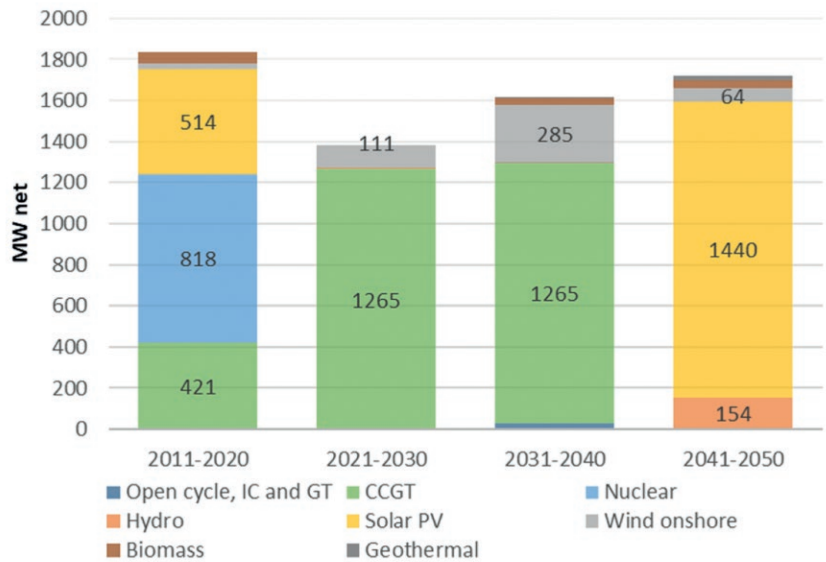
Figure 22. Net electricity generation by plant type, reference scenario, 2015 to 2050, in TWH and shares
Shifts in the power generation mix from nuclear to CCGT to solar in the reference scenario



Source: E3-Modelling, CPS Technical Report.

Power sector investment shifts over time in the reference scenario, from nuclear to CCGT to solar. The investment expenditures for power generation plants increase significantly until 2020, due to the commissioning of the new nuclear reactors at Mochovce. In the medium term, the model-projected commissioning of CCGT requires the bulk of investment. At the end of the projection period, renewables penetration (mostly solar) drives investment expenditures (*Figure 23*).

Figure 23. Newly installed capacity in electricity, reference scenario, by decades to 2050, in net MW
Investment in electricity capacity is concentrated in CCGT in the medium term and solar in the long term in the reference scenario



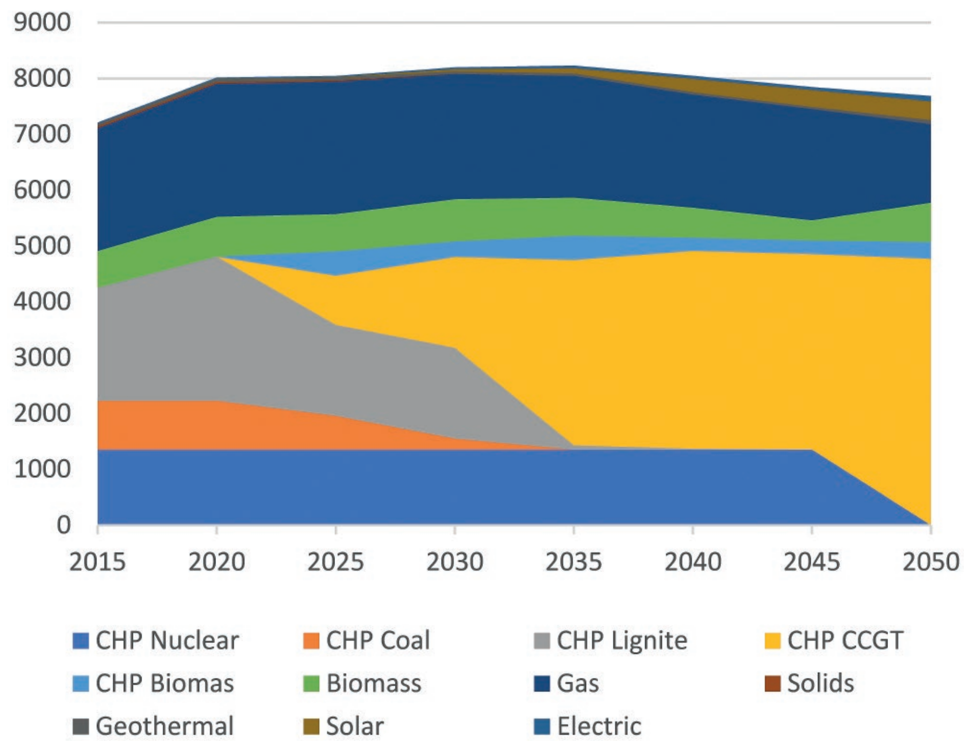
Notes: Net MW is the maximum output of electricity net of power consumed within the plant.
Source: E3-Modelling, CPS Technical Report.

Heating is analyzed in detail for the reference scenario. The CPS model distinguishes between heat consumed in residential, services and agriculture sectors via the district heating network, and steam consumed in the industrial sectors and the refineries. Heat and steam are produced by cogeneration power plants, boilers and heat pumps. The CPS model assumes that the cogeneration plants operated by power utilities supply heat to the district heating sector and that industrial cogeneration plants specified by industrial sector produce the industrial steam. The latter are specific to the sectors and are not operated by utilities. Similarly, the boilers for heat are operated by district heating, and the boilers for steam are distinguished by sector and operated by their respective industries. In other words, the cogeneration plants and the industrial boilers are located on industrial sites and can only supply steam to the industrial sector to which they belong. Industries are able to purchase electricity from the grid or to self-generate. In the former case, the industry may enjoy low supply tariffs, but in the latter, the industry reduces total energy costs by cogenerating industrial steam together with the self-produced electricity. In some sectors, there is also a possibility of using industrial by-products, such as gases in iron and steel, refinery gas in refineries, or waste in pulp industry, which are not tradable commodities.

Heating demand rises in the medium-term and then moderates by 2050 as energy efficiency strengthens. The demand for distributed heat (district heating) rises slightly in the reference scenario in the medium-term as part of the increasing trend of total energy consumption in buildings. In the long-term, the demand for distributed heat declines modestly, as the progress of energy efficiency reduces total energy demand and part of the buildings is increasingly electrified in the heating uses. In 2015, cogeneration plants covered almost 60 percent of heat demand; they are more competitive than heat-only producing boilers due to the value of the electricity production. As a result, the market share of combined heat and power (CHP) sees a rising trend over the entire projection period in the reference scenario (*Figure 24*).

Over the reference scenario period, CCGT plants replace fossil fuel-powered plants. Solid-fuel CHP plants, boilers using natural gas, and the Bohunice nuclear plant are the main suppliers of heat in 2015. Solid fuel plants are phased out, but power and heat cogeneration remains profitable, and four out of the six new CCGT plans have cogeneration. Boilers using natural gas maintain their share; biomass boilers do not show a significant market penetration, due to the absence of policies supporting biomass. Solar thermal heat plants generation emerges after 2035, driven by the high ETS prices. At the same time, industrial CHP plants continue to produce steam, the demand for which is stable or slightly declining in the projection mainly due to heat recovery investment and the use of highly efficient equipment. After 2035, the rising ETS prices also add to the factors implying a decrease in steam demand in the energy intensive industries. The industrial CHP plants cover roughly two-thirds of total steam demand over the entire projection period. The fuel mix of cogeneration plants and steam boilers is mainly gas, biomass, and waste. Gas inputs include self-produced gas in some industries. The projection displays a significant increase in the use of biomass and waste for steam production in industry because of rising ETS prices (*Figure 24*).

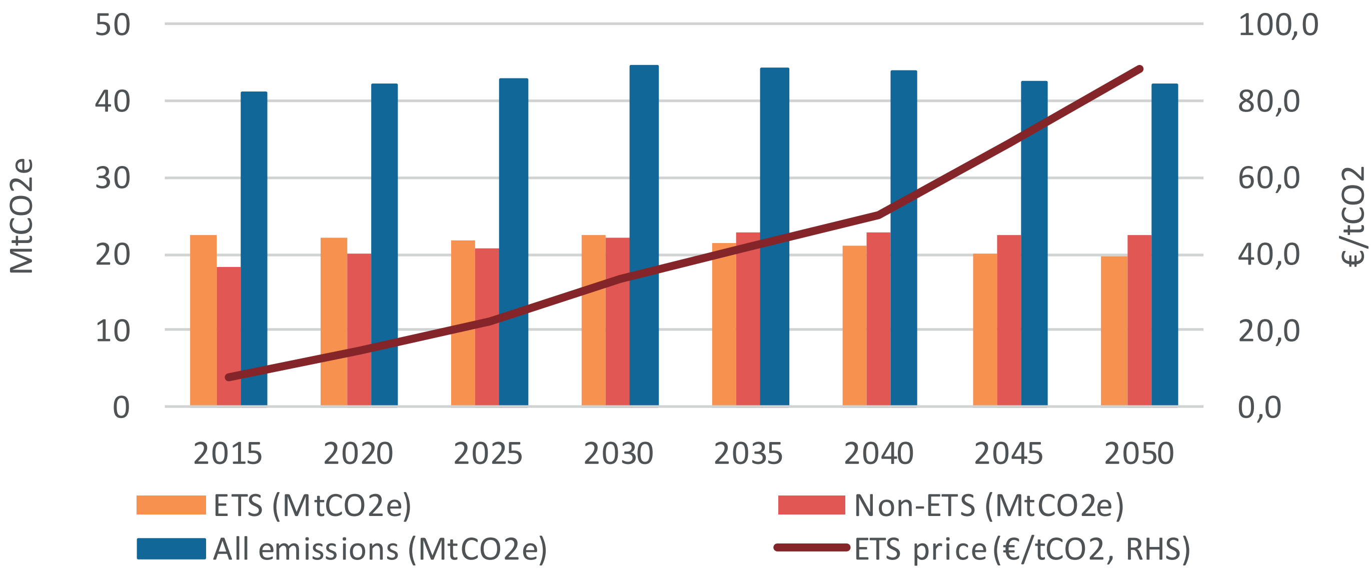
Figure 24. Heat generation by plant type, 2015-2050, in GWh
Overall heating demand rises and then moderates while CCGT plants take over from other fuels



Source: E3-Modelling, CPS Technical Report.

Without supporting policies after 2020, the ETS price is not sufficient to drive significant reductions in total GHG emissions. The ETS operates subject to the Market Stability Reserve mechanism through 2050, and the steadily rising ETS price has a strong influence on the ETS sectors (power generation, heat supply and energy-intensive industry). The evolution of ETS prices causes a considerable emissions reduction in these sectors during the entire period after 2020. However, while emissions from ETS sectors continue to fall, those from non-ETS sectors increase over the projection period, leaving total emissions little changed through 2050 (seven percent lower in 2050 than 2015)[16] with cumulative emissions during 2015-2050 of about 1000 Mt CO_2e (*Figure 25*).

Figure 25. Emissions and ETS price, reference scenario, 2015 to 2050, in MtCO_2e and € per metric ton
ETS price alone drives only a small reduction in total emissions in the reference scenario



Notes: All emissions is total GHG emissions excluding LULUCF.
Source: Slovak-CGE model results and CPS model results.

16. The EU Reference Scenario 2016 projects an 11 percent decline during 2015 t0 2050.

CHAPTER 4

POLICY SCENARIOS TO MEET SLOVAKIA'S CLIMATE COMMITMENTS

The European Union's 2016 'Winter Package' to support the transition to clean energy requires Member States to choose targets for energy efficiency and renewables and defend those targets. The CPS and Slovak-CGE models can assist Slovakia in that task. Four decarbonization scenarios for Slovakia have been designed as contrasting combinations of energy efficiency and renewables targets, representing the trade-offs between targets. All four decarbonization scenarios necessarily focus on the energy sector, and all include construction of new nuclear generation capacity for Slovakia, sustaining the key role of nuclear energy in the generation mix. Substantial investments in energy efficiency are also needed by businesses and households to achieve reductions in energy demand.

Moving to a low carbon economy can support somewhat higher GDP in the long term. However, it could also lead to lower household consumption, especially during the transition when investment is higher. Decreased demand for fossil fuels reduces Slovakia's import bill. Within investment, some crowding out of non-energy investment may occur, as the country pushes forward on investing in decarbonization. The structure of aggregate demand shifts under all the scenarios, in turn affecting industry outputs; and the changes in the industrial structure of the economy leads reallocation of labor and capital across industries. The government is assumed to increase taxes or reduce transfers to ensure sustainability of the government budget during the transition to a low carbon economy.

ETS emissions in Slovakia by 2050 are projected to decrease by about two-thirds compared to the reference scenario, while non-ETS emissions decrease by about one-quarter. Decarbonization implies specific policies. In all scenarios, there is a significant push by the transport sector to improve energy efficiency. Four combinations of policies were assessed (creating the four decarbonization scenarios). Up to 2030, the most important area for policy in Slovakia is renovation of buildings. All policy scenarios demonstrate roughly the same level of emissions reduction. Energy consumption in the policy scenarios decreases significantly relative to the reference scenario, following also a declining trend over time. Moving from DCarb4 to DCarb1 policy scenario, the reduction of final energy demand intensifies as a result of the introduction of additional policies promoting energy efficiency improvements. In the medium term, electricity demand increases at lower rates than in the reference scenario. In the medium – term, the renewable policies enable the penetration of biomass plants into the power mix, substituting for CCGT generation. The scenarios differ in their impact on Slovakia's energy system, but their macroeconomic impacts are similar over time except for variations in investment in later years. Overall, GDP increases above baseline by approximately 0.5 to 1.0 percent during 2025-2035 and by three to four percent during 2040-2050. There are, in addition, significant effects on the structure of the economy. All four scenarios involve a reduction of consumption (of three to six percent compared to the reference scenario during 2040-2050). Lastly, decarbonization has varied effects across industries.

SCENARIO DEFINITIONS

Under the 2016 'Winter Package,' Slovakia needs to choose targets for energy efficiency and renewables and defend those targets, and the CPS and Slovak-CGE models can assist in that task. Member states need to submit to the EU their targets and the related policy instruments that would drive the achievement of the targets. Moreover, member states must also submit an impact assessment of the policy instruments. Various combinations of targets are possible to adopt at the national level, with corresponding policy instruments. These combinations of targets form scenarios that can be analyzed using the CPS and Slovak-CGE models, which are tools specifically developed to support future national submissions for the package. The policy scenarios include ways of achieving various combinations of efficiency, renewables and emission reduction targets in 2030. The policy scenarios also consider achievement of the EU's 2050 target for emission reductions.

The four decarbonization scenarios analyzed for Slovakia have been designed as contrasting combinations of energy efficiency and renewables targets, representing the trade-offs between targets. All scenarios include Slovakia's participation in the ETS, while each scenario differs in their targets for renewable energy and energy efficiency. To illustrate the trade-offs, an ambitious energy efficiency target is combined with a low renewables target (Decarbonization 1); median targets for renewables and energy efficiency are also analyzed (Decarbonization 2); a low energy efficiency target and an ambitious renewables target (Decarbonization 3) and moderate energy efficiency and very ambitious renewables (mainly in electricity) (Decarbonization 4). By design, each scenario achieves a similar reduction in GHG emissions (*Table 5*) and similar total energy system costs. (See Annex 1 for a non-technical explanation of the policy scenarios).

Table 5. Key policy targets and outcomes by policy scenario

Decarbonization scenarios differ on targets for renewables and energy efficiency

Policy indicators	2015	2020	2030				
			Reference	DCarb1	DCarb2	DCarb3	DCarb4
Total CO_2 emissions from energy combustion (% change from 2005)	-27.29	-27.75	-27.81	-39.02	-40.80	-40.59	-41.48
ETS sectors, CO_2 emissions from energy (% change from 2005)	-30.78	-34.88	-38.40	-50.58	-53.46	-53.51	-54.99
non-ETS sectors, CO_2 emissions from energy (% change from 2005)	-21.39	-15.71	-9.91	-19.49	-19.42	-18.77	-18.66
Overall RES share (%)	14.03	14.49	14.34	16.33	18.91	19.83	21.85
RES-H&C share (%)	14.16	13.24	14.04	16.89	20.65	22.07	19.55
RES-E share (%)	19.43	23.38	21.28	22.62	24.81	25.32	36.79
RES-T share (%)	8.26	10.05	10.20	11.49	11.74	11.80	13.12
Primary energy savings (%)	0.00	-20.16	-24.91	-30.32	-28.36	-27.25	-28.88

Notes: RES-H&C is renewable energy sources for heating and cooling. RES-E is renewables for electricity generation. RES-T is renewables in transport. Primary energy savings is compared to PRIMES 2007 baseline projections.

Source: E3-Modelling, CPS Technical Report.

Modeling of decarbonization policies for the rest of the EU is pursued in a simpler manner. For the rest of the EU, the same level of detail in modeling of decarbonization policies as for Slovakia is unavailable (because the CPS model covers Slovakia only). The cost of policies is imposed through the ETS CO_2 price, common for all EU countries. The difference is that the response to such a carbon tax is modeled in a less explicit and detailed way than in the CPS model, i.e. using a top-down approach to the modeling of inter-fuel or capital-energy substitution. Emission reductions in non-ETS sectors for countries other than Slovakia were imposed, facilitated in a simplified way in the model by imposing an emission tax for those sectors (with the rate determined endogenously by the Slovak-CGE model). The assumed emission reductions versus the reference scenario were based on a comparison of policy simulations undertaken by the European Commission with the EU Reference Scenario 2016.[17]

The two models are applied in a coordinated fashion, with the CPS providing detailed energy outputs to the CGE model. The CPS model is first solved to show the effects of decarbonization policies on the energy sector. Next, the CGE model run uses CPS results on energy intensities by sector and energy type (where intensity is measured either as energy use per unit of sector value added or per unit of GDP), investments in electricity and heat generation, electricity and heat generation mix, average unit cost of electricity and heat generation, investments in energy efficiency, and energy use by fuel, by sector. The Slovak-CGE model also uses the CPS assumptions regarding the ETS CO_2 price, which is uniform across decarbonization scenarios but significantly higher than in the reference scenario. The CGE simulation shows how output by sector adjusts, but these output changes are not iterated back to the CPS model (because the results were already similar). Consequently, energy demand levels are not identical between the CPS and CGE models, although energy intensities are identical (and the same relates to emissions). In this way, the CGE simulations show how the economy responds to a shock consisting of changes in the cost of energy and the choice of energy-related technologies (driven by carbon prices and other regulation).

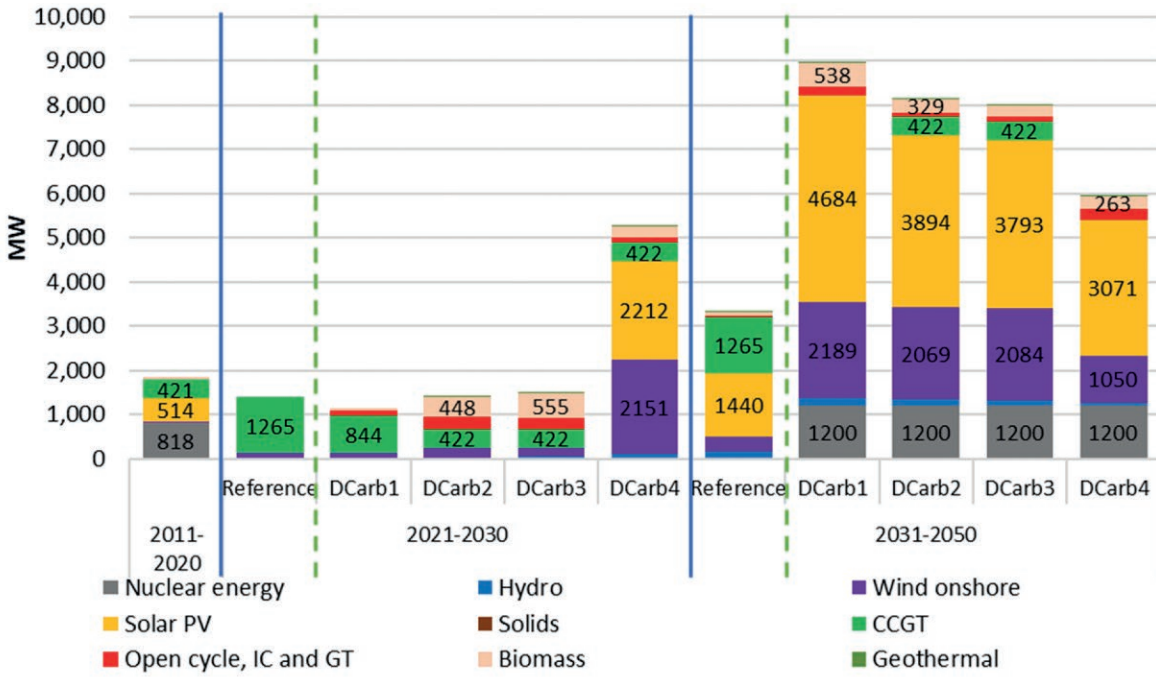
MAIN FINDINGS

All four decarbonization scenarios involve the construction of new nuclear generation capacity for Slovakia, continuing the importance of nuclear energy in the generation mix. This investment in nuclear displaces investment in CCGT compared with the reference scenario. The four decarbonization scenarios do differ in the extent to which renewables enter the generation mix. The importance of renewables increases from Decarbonization 1 to Decarbonization 4. In particular, Decarbonization 4 focuses on achieving the renewables target through the electricity sector and results in greater penetration of renewables, particularly wind. (*Figure 26*).

17. The policy simulations that were used for the rest of the EU were the EUCO scenarios. The European Commission created two core policy scenarios in 2016, EUCO27 and EUCO30, using the PRIMES model, with the EU Reference Scenario 2016 as a starting point. The EUCO scenarios include achievement of the 2030 climate and energy targets and a 27 or 30 percent energy efficiency target. ec.europa.eu/energy/en/data-analysis/energy-modelling.

Figure 26. Newly installed capacity in electricity, by scenario, 2011-2050, in net MW

Investment in electricity capacity in the policy scenarios diverges from the reference scenario in magnitude and earlier solar PV



Source: E3-Modelling, CPS Technical Report.

Substantial investments in energy efficiency are also needed by businesses and households to achieve reductions in energy demand. For industry, such as heavy manufacturing, this involves focusing on best available techniques through investment in heat recovery, processing and new equipment. For the tertiary sector (e.g. services sector), this mainly involves building renovations (i.e., improved insulation). Households undertake substantial house renovations to achieve the 2030 targets, while post-2030, there is a strong uptake of electric cars and fuel cell cars, replacing internal combustion engine cars. Notably, the electrification of the transport sector is common across scenarios since they are driven by policies at the EU level. The ambitious energy efficiency target of Decarbonization 1 compared to the other scenarios is reflected in the higher level of investment in building renovations by households and the tertiary sector, as well as higher investments in heat recovery in industry (*Table 6*).

Table 6. Investments by subsector or type, by scenario, 2015, 2030 and 2050, in € millions and thousands of vehicles

Renovation, industrial heat recovery and electrification of transport allow Slovakia to meet its energy efficiency targets

	2015	2030					2050				
			Decarbonization scenario:					Decarbonization scenario:			
		Ref	1	2	3	4	Ref	1	2	3	4
Investments (M€)											
Heat recovery	-	115	954	292	116	85	126	1178	984	847	809
Processing	970	1555	1457	1470	1488	1490	1957	2234	2197	2198	2202
Equipment & appliances	3429	7811	7865	7855	7856	7850	9811	9704	9698	9697	9702
Building renovation by households	-	205	295	829	485	580	223	6033	2795	1256	1584
Building renovation in tertiary sector	-	257	3971	832	582	727	285	3498	1511	996	813
Passenger cars (thousand of vehicles)											
Electric cars	-	37	56	56	56	56	211	1641	1646	1643	1644
Fuel cell cars	-	0	0	0	0	0	73	350	347	350	347
ICE plug in cars	-	69	99	99	99	99	263	371	370	371	370
ICE cars	1754	2409	2357	2357	2357	2357	2561	1211	1211	1209	1212

Note: ICE are internal combustion engine passenger cars.

Source: E3-Modelling, CPS Technical Report.

The demand for heat and steam declines in all the policy scenarios, driven by ever rising energy efficiency. The demand for distributed heat maintains its position in share terms. The supply of distributed heat needs to comply with the rising ETS carbon prices and to deliver in terms of the renewable targets. Cogeneration technology is more efficient than boilers, and thus the policy scenarios project that the CHP plants for heat production continue to have a significant place in the heat supply. However, they change fuels increasingly towards renewables and, in particular, biomass. New clean heat production technologies emerge in the scenarios, such as electric boilers, high-temperature heat pumps and geothermal energy. Similarly, in the supply of industrial steam, cogeneration maintains its share but changes fuel in favor of biomass. Self-production of electricity in industry is less competitive in the long-term than under current conditions, since electricity generation, being subject to high ETS prices, transforms using RES and nuclear, putting downward pressure on prices for industrial electricity. Thus, industrial steam production declines in the long-term and shifts strongly towards biomass boilers (*Figure 27*).

Figure 27. Heat and steam generation, levels and shares by generation source and by fuel, by scenario, 2020, 2030, 2050

Biomass use for heat and steam and new clean heat production technologies expand under all scenarios

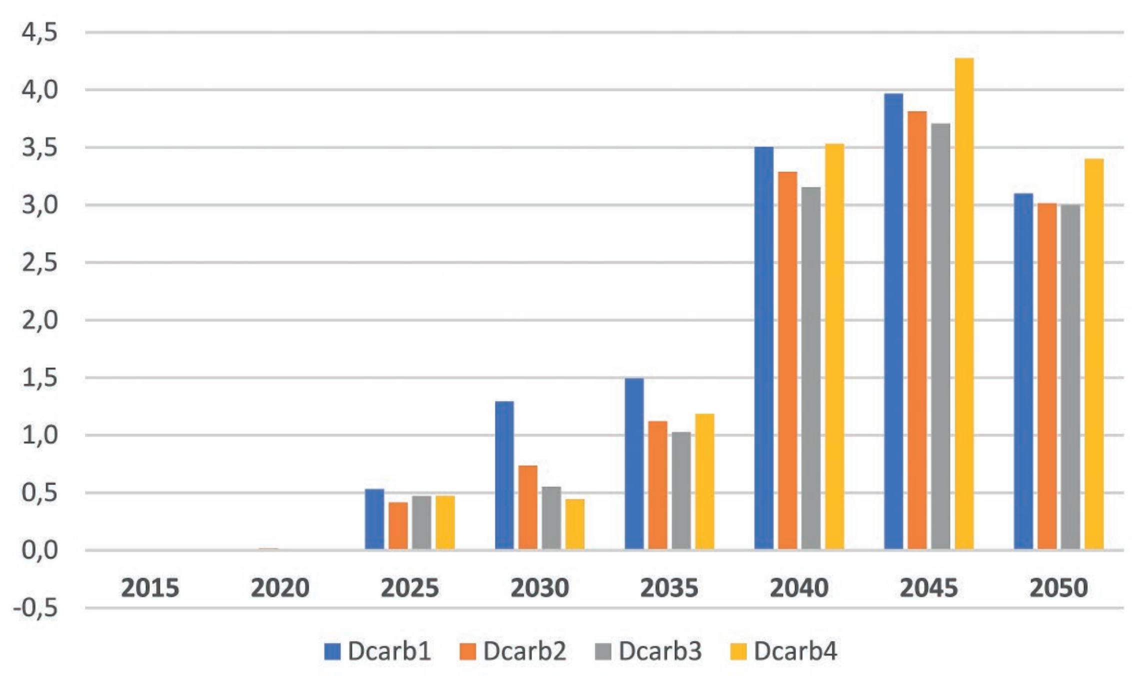
Source: E3-Modelling, CPS Technical Report.

Moving to a low carbon economy can potentially support higher GDP in the long term but could also lead to lower household consumption.[18] Investments in energy efficiency reduce energy costs and lead to long term gains in the productivity of the economy. In the short to medium term, these investments

18. Given the design of the CGE model, changes in real private consumption should be considered welfare changes. Labor supply is exogenous, so leisure is not explicitly part of the utility function. Furthermore, real government consumption is fixed across scenarios.

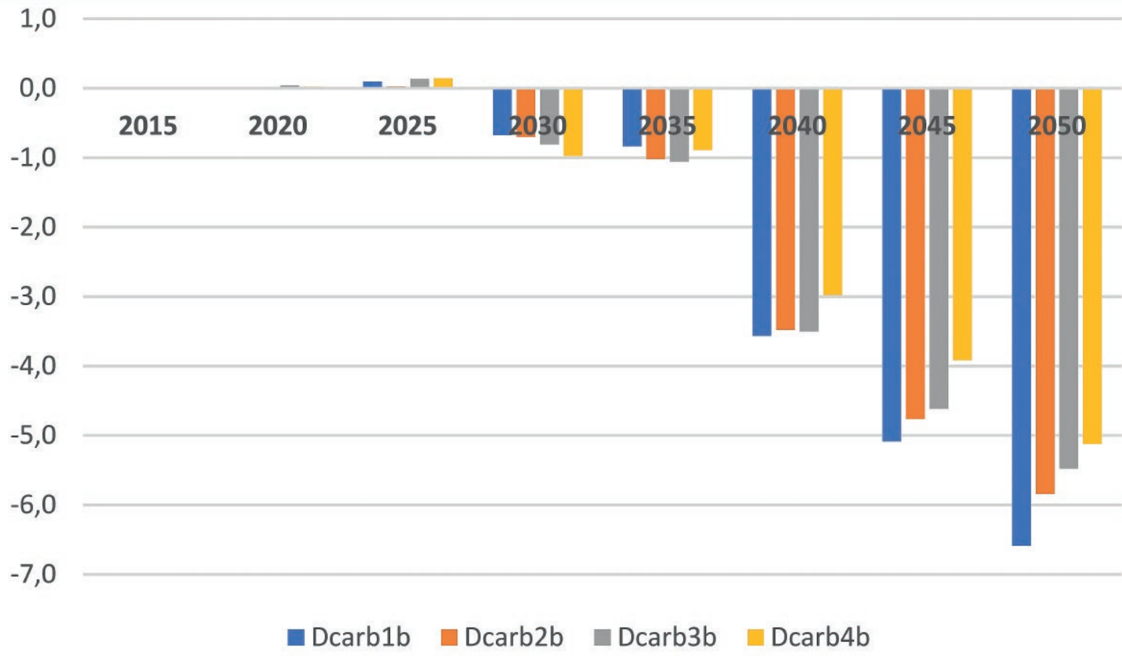
need to be funded. For industry and the tertiary sectors, these energy efficiency investments are passed on to consumers of their products in the form of higher prices. For households, they effectively fund the building renovations on their homes through a reduction in consumption. The cost of electrification in the transport sector is also felt by households, but this does not lead directly to a reduction in consumption. Rather, households replace their ICE (Internal Combustion Engine) vehicles with either an electric vehicle or fuel-cell vehicle (*Table 6*). However, households are also affected by the higher prices passed on by businesses to recoup the cost of energy efficiency investments. Hence, all four scenarios involve a reduction of consumption (of three to six percent compared to the reference scenario during 2040-2050). The fall in household consumption is largest in Decarbonization 1 since this scenario includes an ambitious target for energy efficiency which requires the largest investment. Notably, the size of the investment needed in electricity generation is dwarfed by the investments needed to improve energy efficiency. Overall, GDP increases above baseline by approximately 0.5 to 1.0 percent during 2025-2035 and by three to four percent during 2040-2050 (*Figure 28, Figure 29, Figure 30*).

Figure 28. GDP, by policy scenario, 2015-2050, in % change from reference scenario
GDP impact is positive in the medium-term for Decarb1 and for all policy scenarios over the long-term



Source: Slovak-CGE model results.

Figure 29. Private consumption, by policy scenario, 2015-2050, in % change from reference scenario
Consumption is reduced under all policy scenarios

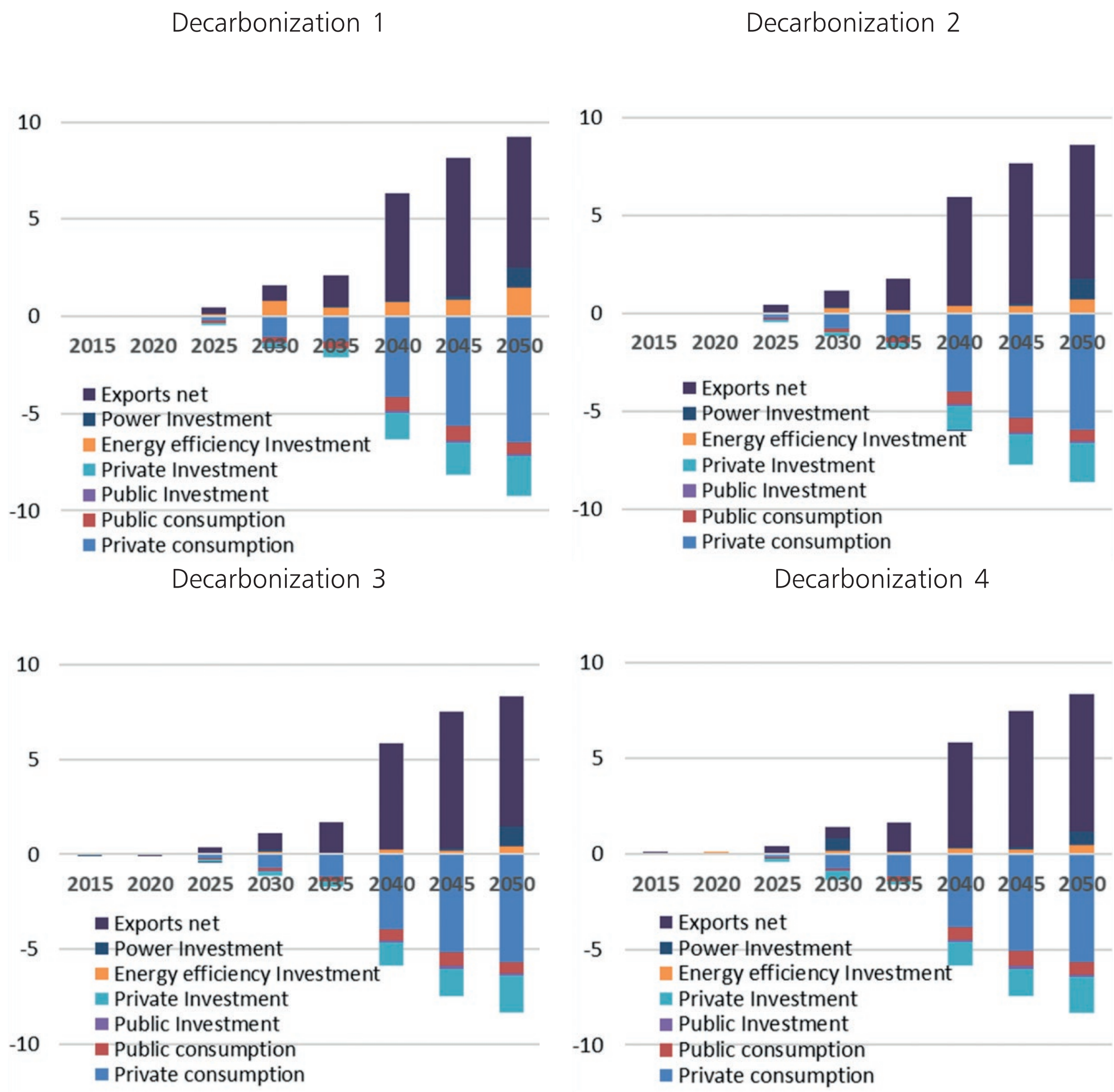


Source: Slovak-CGE model results.

Decreased demand for fossil fuels reduces Slovakia's import bill; however, the terms of trade also deteriorate. The worsened terms of trade imply that – from the macroeconomic perspective – more factor resources need to be used for export activities to trade for a given amount of imported goods. Consequently, imports drop further, while exports increase. The increase in net exports, related to terms of trade deterioration, "consumes" the GDP gain, stemming from productivity (energy efficiency) improvement and contributes to the drop in private consumption.

There can be some crowding out of non-energy investment, as Slovakia focuses on investing in decarbonization. Energy efficiency and power sector investments are significant—from 0.3 to over 2.0 percent of GDP across scenarios and years. The increase in prices as firms recoup the cost of investing in energy efficiency reduces Slovakia's competitiveness and impacts on firm's profitability. In addition, the fall in household consumption reduces demand, also creating a drag on profitability. The reduction in profitability discourages foreign investors from investing in the Slovak economy. Similarly, investment in electricity generation crowds out some non-energy investment.

Figure 30. Expenditure shares in GDP, by policy scenario, 2015-2050, in % change from reference scenario
Net export shares are boosted over the long-term, more than compensating for reduced consumption



Source: Slovak-CGE model results.

Changes in industry outputs are affected by the shift in the structure of aggregate demand. The drop in consumption lowers the demand for market services (including both personal services and trade services[19]) and transport services. Market services' share of value-added is lower by 1.8 to 2.2 percentage points in the decarbonization scenarios compared to the reference scenario in 2050. Decarbonization does lead to a reduced importance of some heavy manufactures such as chemicals, rubber and plastic sector and iron & steel. Iron & steel experiences high extra investment cost, leading to significant price increases, and

19. Trade services correspond with retail or wholesale trade margins.

petroleum refining faces lower demand for oil fuels. On the other hand, in some other cases – notably the non-ferrous metals sector – the energy system cost actually drops as a result of decarbonization policies, leading to price decreases and output expansion. Moreover, the increased cost of energy efficiency investment for heavy manufactures is mitigated by lower labor costs, related to lower wages, or – more generally – real depreciation that the Slovak economy experiences as a result of decarbonization policies. Motor vehicle manufacturing maintains its importance in the Slovak economy across all four scenarios. The implicit assumption is that the Slovak motor vehicle manufacturing industry would shift towards the production of electric vehicles in line with demand. Households and the transportation sector purchase electric motor vehicles rather than traditional motor vehicles; hence the industry's share of value added is stable across reference and policy scenarios. The results for industries supplying investment goods are rather mixed. In the decarbonization scenario which involves substantial investment in building renovation, the construction sector expands. Construction is boosted by the renovation of buildings, both by households and businesses. However, in the remaining scenarios, the crowding out of private investment outweighs the boost from the decarbonization-related investment (*Table 7*).

Table 7. Value added shares in GDP, by sector and policy scenario, 2030 and 2050, in % change from reference scenario

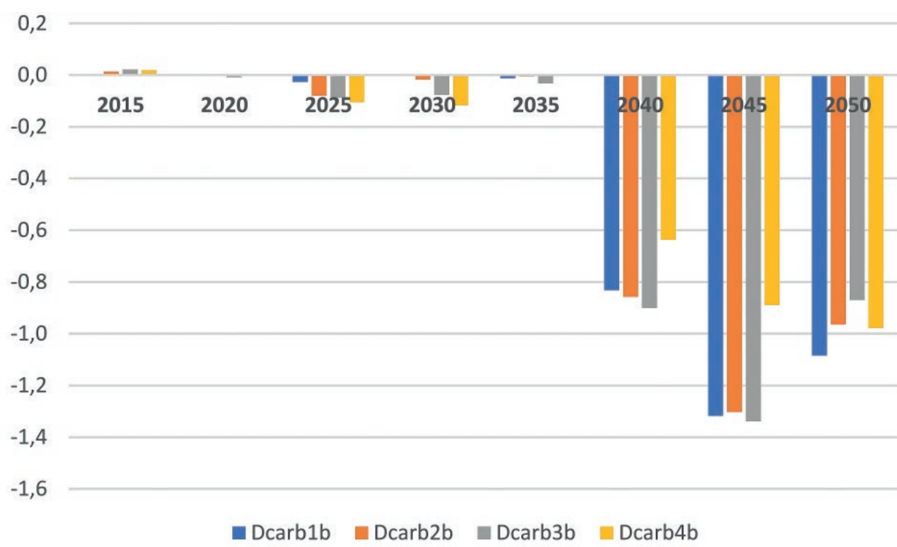
Industry responds to the altered structure of GDP

Change in share of value added (in percentage points) *by policy scenario*	2030				2050			
	Decarb1	Decarb2	Decarb3	Decarb4	Decarb1	Decarb2	Decarb3	Decarb4
Agriculture	0.01	0.06	0.07	0.03	0.08	0.11	0.11	0.08
Energy	-0.06	0.17	0.26	0.61	0.97	1.02	1.04	1.06
Other manufacturing	-0.03	-0.04	-0.05	-0.08	0.75	0.78	0.80	0.84
Chemical, rubber, plastic	0.08	0.04	0.02	0.10	-0.24	-0.23	-0.22	-0.23
Non-metallic minerals	0.01	0.01	0.01	0.01	0.10	0.11	0.11	0.11
Iron and steel	0.03	0.01	0.00	0.04	-0.18	-0.16	-0.14	-0.15
Non-ferrous metals	0.02	0.02	0.01	0.01	0.15	0.15	0.15	0.14
Motor vehicles	**-0.07**	**-0.05**	**-0.04**	**-0.11**	**0.25**	**0.22**	**0.22**	**0.24**
Equipment	0.00	0.02	0.04	-0.05	0.17	0.17	0.17	0.17
Construction	**0.38**	**0.08**	**0.01**	**0.06**	**0.62**	**0.22**	**0.06**	**0.01**
Transport	-0.01	-0.01	-0.01	-0.05	-0.41	-0.39	-0.39	-0.39
Non-market services	-0.03	-0.03	-0.03	-0.05	-0.03	-0.02	-0.01	-0.04
Market services	**-0.33**	**-0.28**	**-0.30**	**-0.52**	**-2.22**	**-1.98**	**-1.90**	**-1.83**

Source: Slovak-CGE model results.

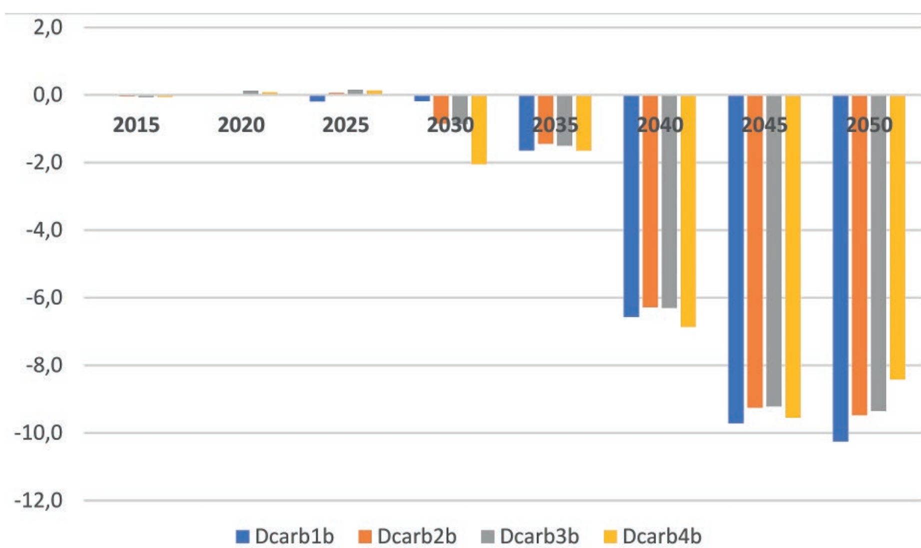
The changes in the industry structure of the economy leads to a reallocation of labor across industries. As can be expected, sectors that expand (mainly export-oriented industries and industries supplying investment goods) attract additional labor, whilst those that contract (mainly industries producing consumption goods) release labor. However, not all workers who are made redundant from contracting sectors are able to find work in expanding sectors, leading to an increase in unemployment. Overall, structural change in the economy in response to decarbonization policies seems to be negative for aggregate labor demand. In the short run (due to lagged wage adjustment), decreased labor demand translates mostly to lower employment. In the long run, by comparison, this translates mainly to decreased wages. The latter effects are substantial and dominate, especially towards the end of the projection period (*Figure 31*, *Figure 32*).

Figure 31. Total employment, by policy scenario, 2015-2050, in % change from reference scenario
Labor is reallocated towards expanding sectors but unemployment rises



Source: Slovak-CGE model results.

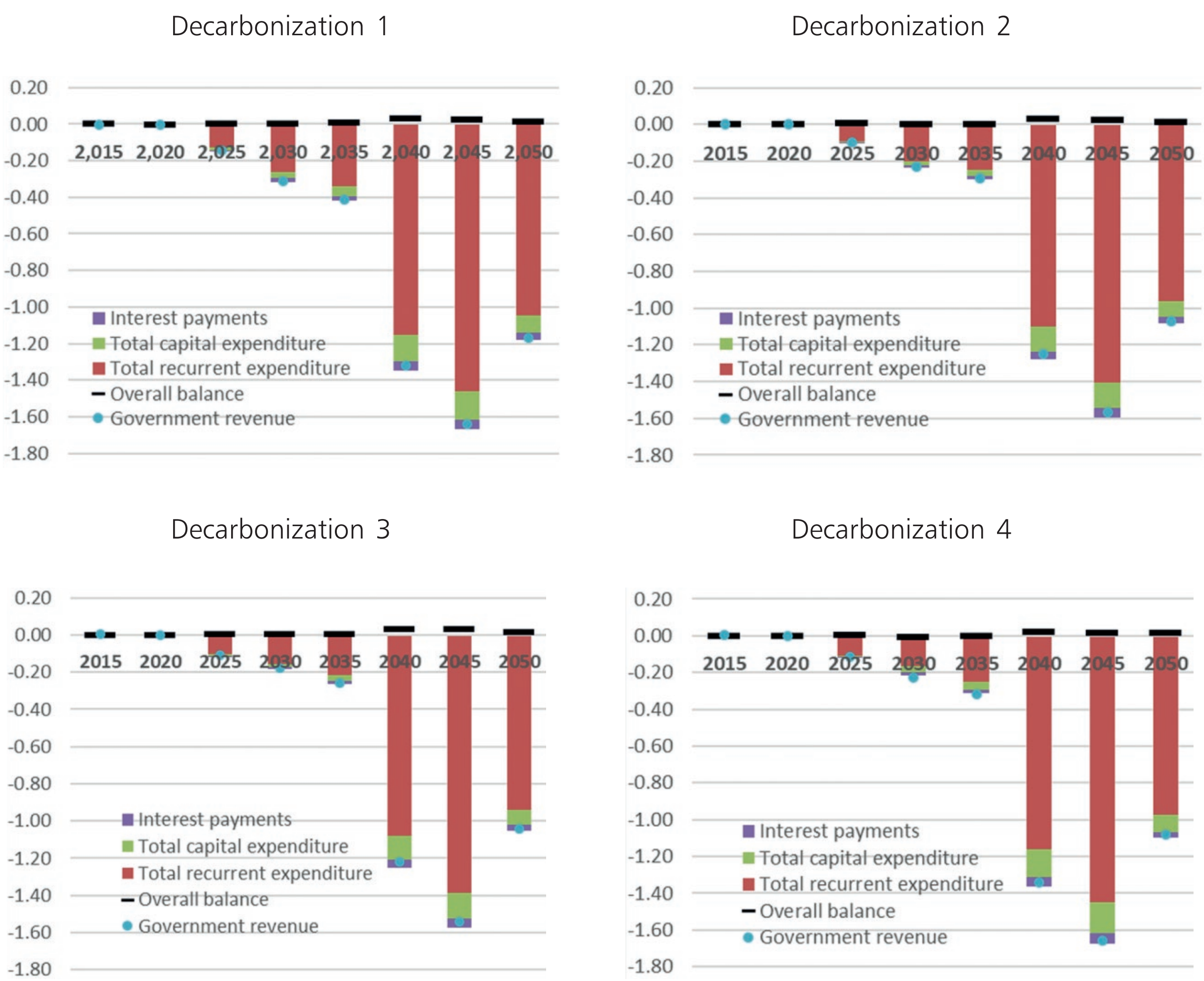
Figure 32. Real wages, by policy scenario, 2015-2050, in % change from reference scenario
Wages fall over the long-term as the labor market adjusts



Source: Slovak-CGE model results.

The government is assumed to increase taxes or reduce transfers to ensure sustainability of the government budget during the transition to a low carbon economy. As a result, the overall government budget balance remains broadly unchanged across scenarios. Another option for the government would be to finance any shortfall through deficits, but this option has not been modelled here. In any case, the increase in government debt would eventually need to be repaid through higher taxation or lower expenditures. The transition to a low carbon economy leads to lower revenue collection from indirect taxes (such as the VAT) and factor taxes (which includes social security contributions). Revenue collection from indirect taxation falls as a result of the reduction in household consumption, while revenue from factor taxes fall due to a lower wage bill. The model does not define what specific change in the taxation or transfer system is imposed to neutralize the impact on budget, except that it is (or is nearly) a non-distortionary (lump sum) instrument. This aspect of the Slovak-CGE model is a simplifying assumption that makes sure the model results are about mitigation policies and not about government deficits (*Figure 33*).

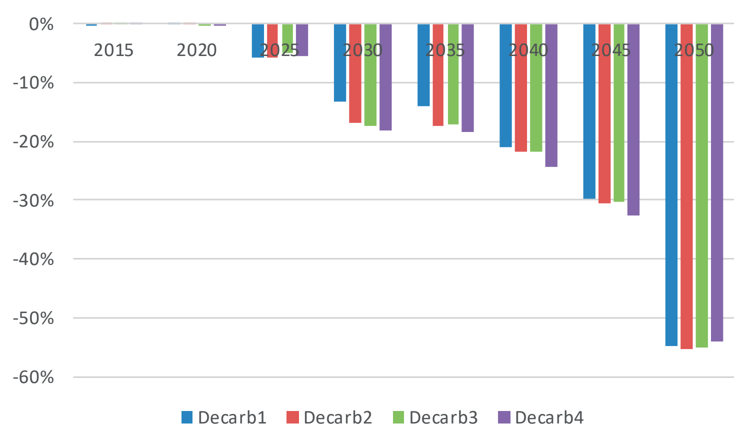
Figure 33. Government budget balance by budget component and policy scenario, 2015-2050, in % GDP change from reference scenario
Revenues from indirect and factor taxes decline



Source: Slovak-CGE model results.

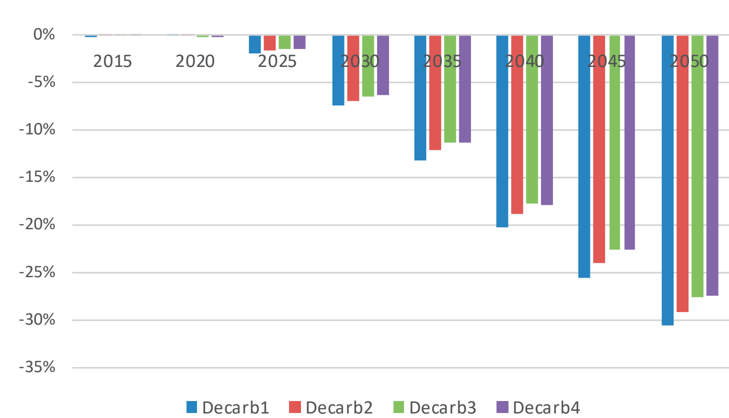
ETS emissions in Slovakia by 2050 decrease by about 55 percent compared to baseline, while non-ETS emissions decrease by 28 to 31 percent compared to baseline. The reporting of GHG emissions combines results from the CPS energy and CGE macro models. The CPS model has the most detailed approach to CO_2 emissions from energy combustion while the CGE model includes non-CO_2 gases (methane, nitrous oxides, and fluoridated gases), as well as non-combustion CO_2 emissions (specifically, process emissions in cement production). Neither model includes other CO_2 emissions (from industrial processes) so an adjustment factor for this and other discrepancies is included to align the modeling results to actual 2015 total GHG emissions. ETS emissions are estimated as a combination of CO_2 energy emissions (from the CPS model), Non-CO_2 emissions (from the CGE model), and the adjustment factor to align with 2015 totals. Non-ETS emissions are estimated as a combination of CO_2 energy emissions (from the CPS model) and Non-CO_2 emissions (from the CGE model). The adjustment factor, to account for industrial process emissions and other discrepancies, is calculated for 2015 to align with actual totals and is projected into the future based on total production of Chemicals, Metals, and Minerals. The adjustment equals six to 13 percent of total GHG emissions. Note that CO_2 is responsible for almost 98 percent of emission reduction (compared to baseline, in 2050) (*Figure 34*, *Figure 35*).

Figure 34. ETS emissions, by policy scenario, 2015-2050, in % change from reference scenario
GHG emissions from the ETS sectors decline sharply in all policy scenarios



Source: Slovak-CGE model results and CPS model results.

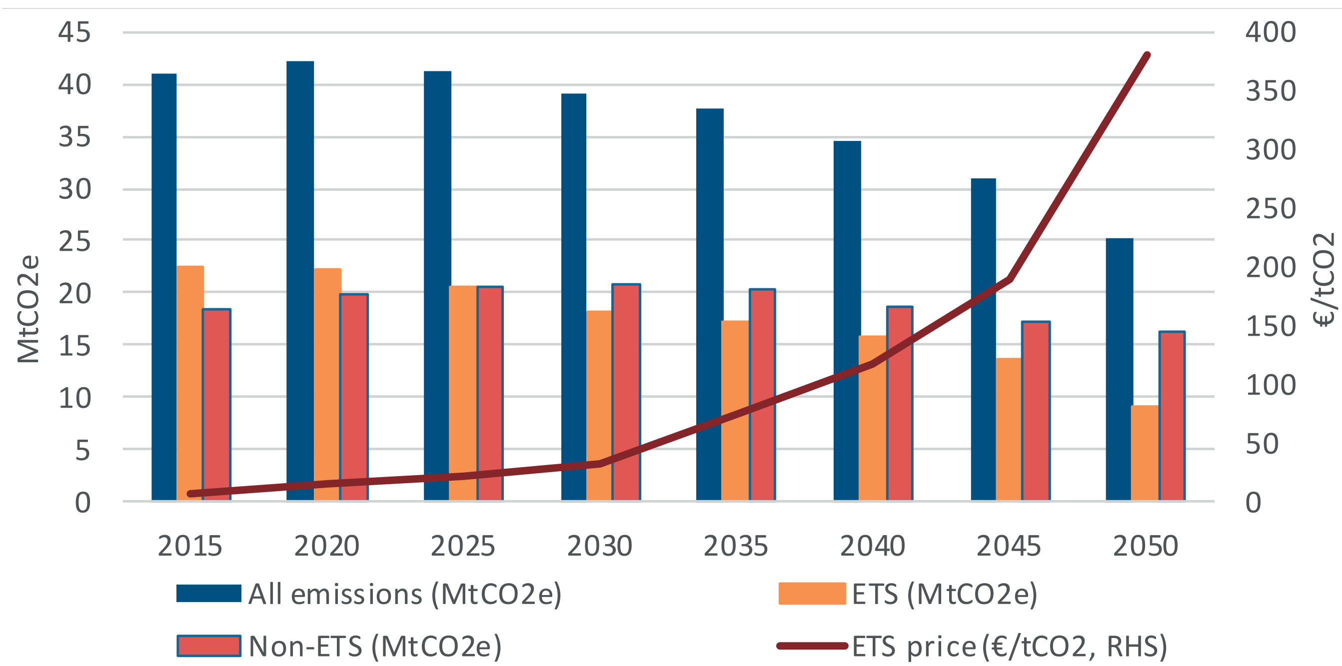
Figure 35. Non-ETS emissions, by policy scenario, 2015-2050, in % change from reference scenario
GHG emissions from the non-ETS sectors also undergo significant reduction



Source: Slovak-CGE model results and CPS model results.

Very high ETS prices and supporting mitigation policies drive down energy-related emissions while other emissions rise modestly through 2050. (*Figure 36*). Combining information from the two models allows a more precise understanding of developments in GHG emissions under the decarbonization scenarios. Under the Decarbonization 4 scenario, ETS emissions fall by 54 percent by 2050 compared to 2015, driven by the ETS price which hits €380 per metric ton of carbon dioxide equivalent in 2050. Over the same period, non-ETS emissions fall by 28 percent (*Figure 36*).

Figure 36. Emissions and ETS price, policy scenarios, 2015 to 2050, in $MtCO_2e$ and € per metric ton
Supporting policies and a high ETS price drive substantial reduction in emissions



Note: Decarbonization 4 scenario, but other policy scenarios are similar.
All emissions is total GHG emissions excluding LULUCF.
Source: Slovak-CGE model results and CPS model results.

Decarbonization implies specific policies and actions to achieve energy efficiency or the renewables targets. Energy efficiency is driven by:

(i) Renovation (e.g., insulation of buildings);

(ii) Eco-design regulations;

(iii) Best available techniques (BAT) in industries such as iron & steel, cement, and aluminum;

(iv) Transport electrification and energy efficiency standards.

The renewables target is achieved through:

(i) Policies promoting renewables in the medium term such as mandatory legislation, infrastructure, easing site access and connections;

(ii) Significant rise in the ETS price in the long-term.

In all scenarios, there is a significant push by the transport sector to improve energy efficiency through:

(i) CO_2 standards for cars and vans, along with efficiency standards for trucks

(ii) Electrification of transport

(iii) Increased use of biofuels.

Four combinations of policies were assessed. A shorthand description of policy scenarios makes use of the fact that the scenarios can be distinguished by the efforts made by industry and households in energy efficiency and the penetration of renewables.

(i) Decarbonization 1: Focus on Energy Efficiency policies, featuring strong uptake of energy efficiency improvements by industries and housing renovation by households

(ii) Decarbonization 2: Balanced targeting of both Renewables and Energy Efficiency

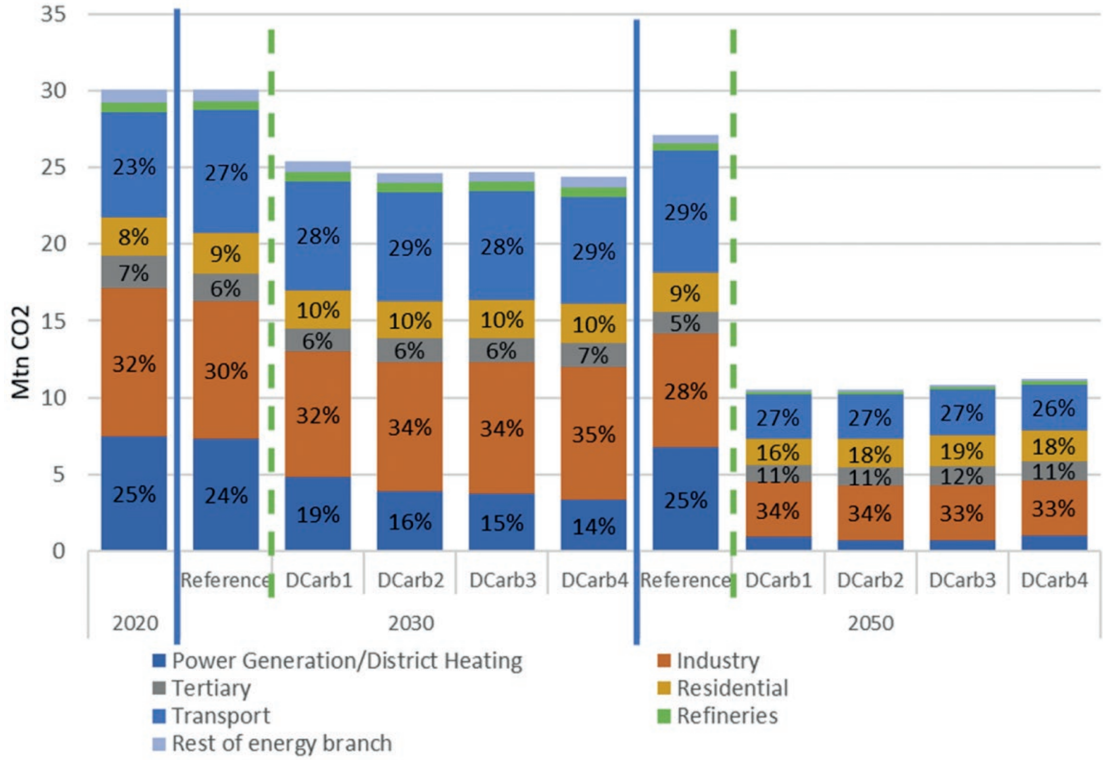
(iii) Decarbonization 3: Focus on Renewables policies, featuring strong uptake of biomass in both electricity generation and heating and cooling

(iv) Decarbonization 4: Achieve Renewables target through Electricity which leads to higher penetration of onshore wind and Solar PV

The most important policy focus up to 2030 is renovation of buildings. Post 2030, it is joined by heat recovery in industry and electrification of transport. Overall number of passenger vehicles remain the same, there is merely a substitution between ICE and electric vehicles. The transport sector is mainly subject to an EU-wide regulation, which does not vary across the scenarios, by definition, hence intensity of electrification is the same across scenarios. In all decarbonization scenarios there is investment in a new nuclear reactor to come on-line in 2050 rather than investments in CCGT in the Reference. Hence, decarbonization scenarios are distinguished by the efforts made by industry, households in energy efficiency, and the penetration of renewables.

All policy scenarios show the same effort towards reducing CO_2 emissions over time. CO_2 emissions in Slovakia are projected to decrease by 65 percent in 2050, compared to 2015 levels, while in the reference scenario emissions were reduced by 11 percent (using the CPS model). The emission reduction is driven by a combination of targets. The EU ETS prices drive the emissions reduction in the ETS sectors, which represent the largest part of total CO_2 emissions. As a result, ETS emissions decrease by 50-53 percent in 2030 and 86 percent in 2050 with respect to 2005 levels. The decarbonization of power generation plays a significant role in the ETS emission reduction. In the non-ETS sectors, reduction of emissions is less dramatic, albeit considerable and a necessary part of overall mitigation in order to deliver the ambitious 80 percent reduction in total by 2050. The emissions reduction in non-ETS sectors are driven mainly by energy efficiency policies which are implemented throughout the projection period in the policy scenario. The reduction achieved is 20 percent in 2030 and an impressive 53-56 percent in 2050 (*Figure 37*).

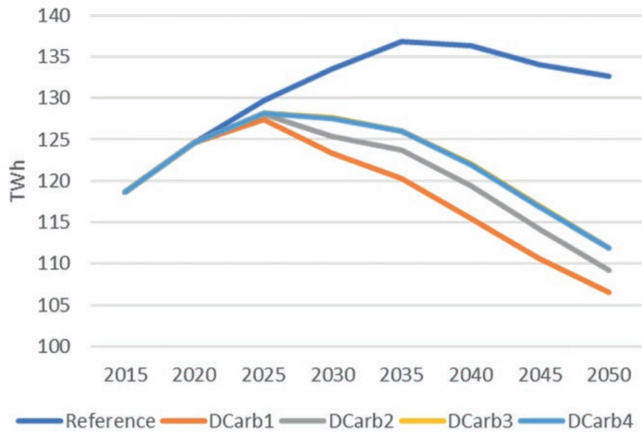
Figure 37. CO_2 emissions by sector, by scenario, 2020, 2030, and 2050, in $MtCO_2$ and shares
Power generation and industry contribute the most to reduction in carbon emissions



Source: E3-Modelling, CPS Technical Report.

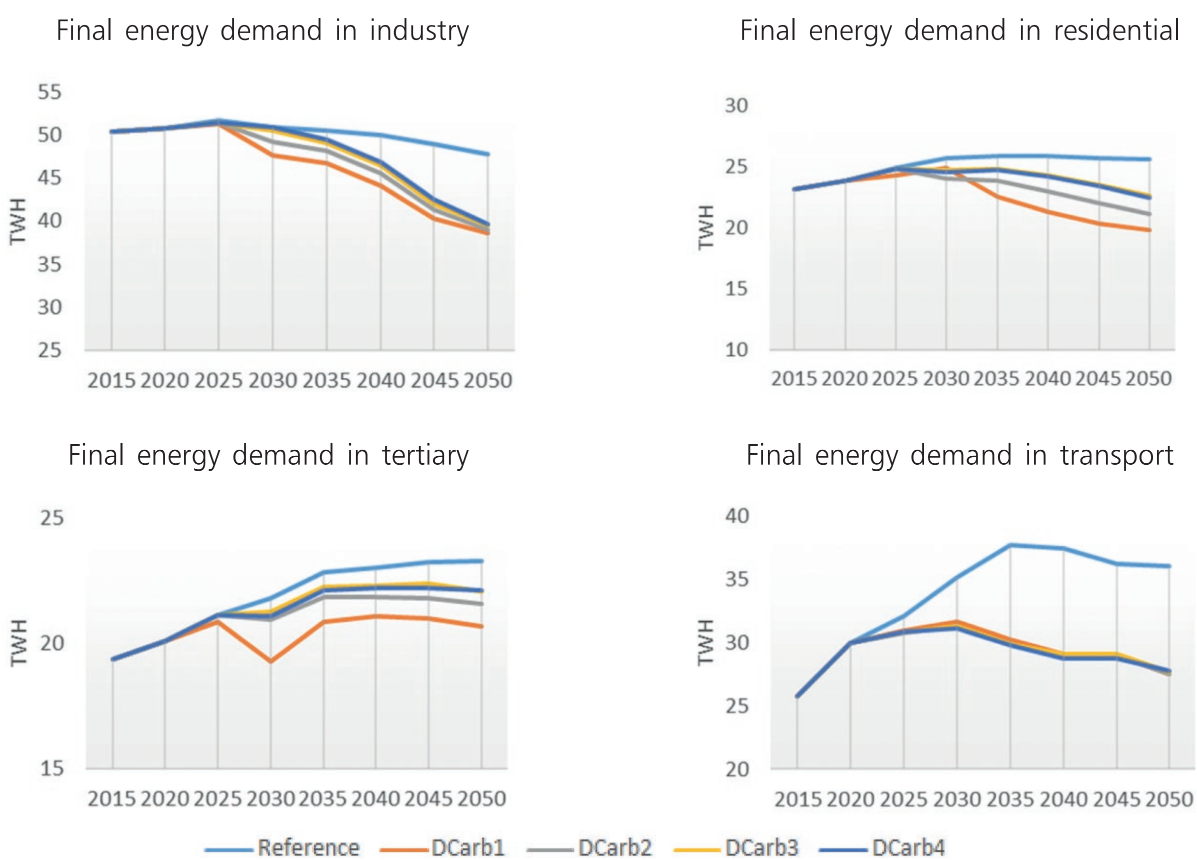
Energy consumption in the policy scenarios is below that in the reference scenario and declines over time, both overall and in the industry, residential, and transport sectors. The introduction of additional policies promoting energy efficiency improvements in the policy scenarios succeeds in controlling rising energy requirements, driven by the improvements of living and working standards, the increase in mobility, and industrial activity. DCarb1 achieves the highest decrease of energy consumption, as it includes the most ambitious energy efficiency policies among the policy scenarios. Final energy demand decreases by eight percent in 2030 and by 20 percent in 2050, compared to the reference scenario. Moving from DCarb1 to DCarb3, the introduction of less ambitious efficiency policies results to lower decrease rates compared to the reference scenario. Although, DCarb4 policy scenario includes the less ambitious efficiency policies, the deployment of variable renewables (Solar PV and wind onshore), substituting the penetration of biomass, contributes significantly to the effort of energy savings (*Figure 38*, *Figure 39*).

Figure 38. Final energy demand, by scenario, in TWh
All policy scenarios save on energy consumption



Source: E3-Modelling, CPS Technical Report.

Figure 39. Final energy demand by sector, by scenario, 2015 to 2050, in TWh
All sectors reduce energy demand



Source: E3-Modelling, CPS Technical Report.

The main outcomes in the scenarios can be summarized:

(i) More stringent efficiency policies drive further the reduction rates of final energy demand in all demand sectors, except transport

(ii) For the transport sector, the additional policies introduced across the policy scenarios are the same; thus, transport demand remains almost stable between the policy scenarios.

(iii) The effort of industry and transport sectors is the most significant among the demand sectors in terms of total energy savings, representing the 60-80 percent of total energy savings across policy scenarios

(iv) CO_2 standards for cars and vans, efficiency standards for trucks, along with the electrification of transport and the increased use of biofuels enable the significant reduction of energy demand in the transport sector.

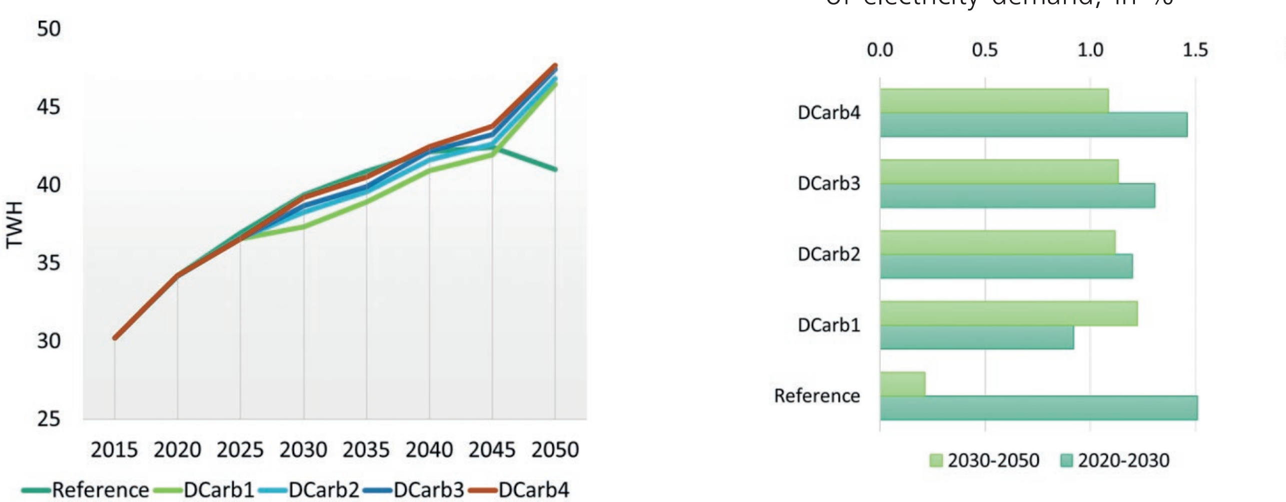
(v) In the industrial sectors, the reduction in energy demand enhances as more ambitious efficiency policies are assumed, indicating increased energy efficiency improvements in the period 2025-2035. After 2035 the energy savings of industry across scenarios do not show significant differences, indicating that the increased EU ETS price trajectory becomes the main driver that enables the use and investment in more efficient technologies.

In the medium term, electricity demand increases at lower rates than in the reference scenario. This outcome comes about as a result of the additional efficiency policies, promoting energy efficiency improvements. Thus, the increase in electricity demand is projected to slow down. The opposite trend is observed in the long term. In all policy scenarios, demand grows at higher rates compared to the reference in the long term. New uses of electricity in heating (i.e. heat pumps), the uptake of appliances and transport electrification not only sustain, but accelerate, the growth of demand for electricity (*Figure 40*).

Figure 40. Electricity demand, by scenario, 2015 to 2050, in TWH and % average annual growth
Electricity demand post-2045 boosted from new uses of electricity

a. Gross electricity demand, in TWH

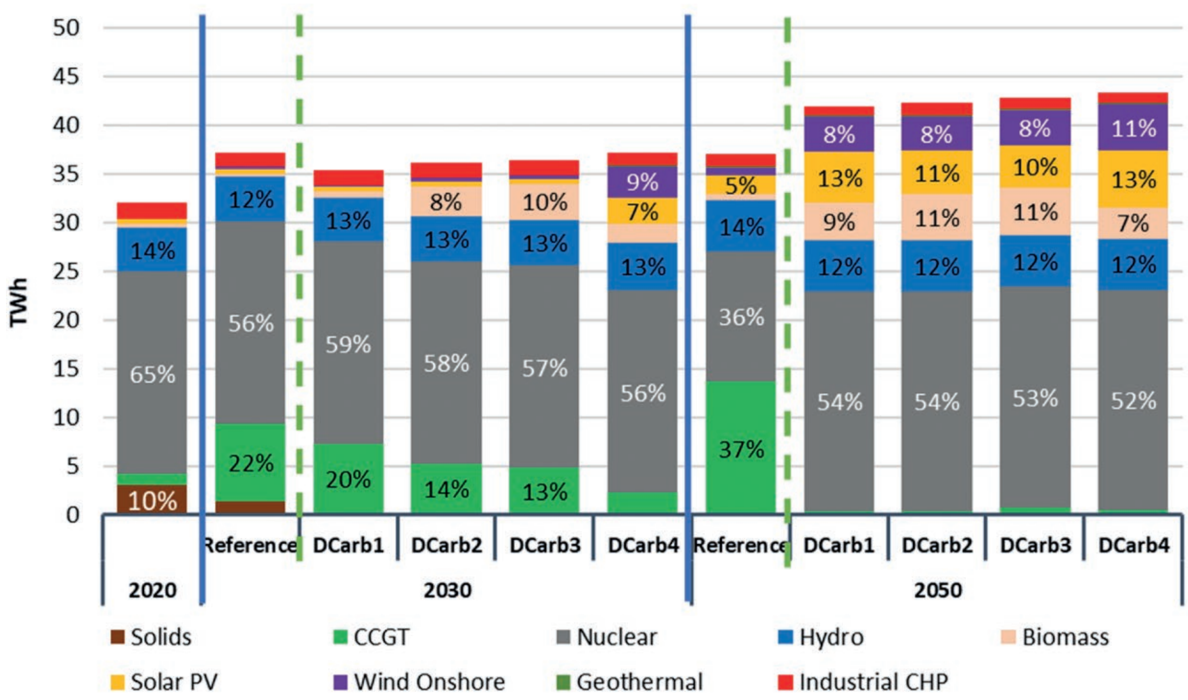
b. Annual average growth rates of electricity demand, in %



Source: E3-Modelling, CPS Technical Report.

In the medium-term, policies on renewables enable the penetration of biomass plants into the power mix, substituting for CCGT generation. Moving from DCarb1 to DCarb3, the biomass-fired generation share increases as renewable policies become more ambitious so as to achieve the RES targets of each scenario. In DCarb4, more stringent renewable policies have been included to achieve the RES target mainly by the increase of the RES – E share. These policies also enable the penetration of variable RES apart from biomass. Thus, biomass penetration is partially substituted by the penetration of onshore wind and solar PV. In the long – term, the RES – based generation share does not vary across policy scenarios, indicating that ETS prices are the main driver enabling RES deployment. Due to increased ETS prices compared to reference scenario and also over time, investment in renewables is more attractive compared to CCGT, despite the fact that CCGT is the fossil fuel-powered generation type with the lowest emissions factor. Another reason driving the decrease of CCGT generation is the endogenous choice of investing in a new nuclear reactor in 2050. As proposed by the Slovak Ministry, a new nuclear plant is possible. In the policy scenarios, the model left unrestricted, so as to choose endogenously whether and when a new nuclear investment would be the most cost – effective option. The increased electricity demand in the long – term and the higher ETS price trajectory compared to the reference scenario enhance the cost – effectiveness of carbon-free nuclear generation (*Figure 41*).

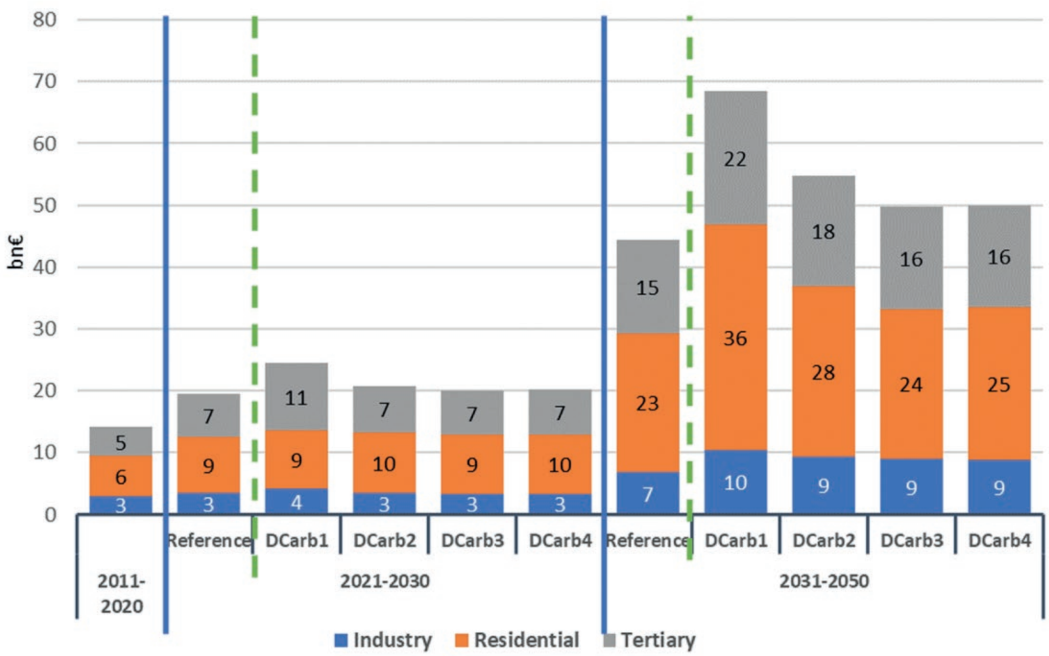
Figure 41. Electricity generation by source, by scenario, 2020, 2030 and 2050, TWh and % shares
Continued importance of nuclear and rising renewables in electricity generation



Source: E3-Modelling, CPS Technical Report.

In all scenarios, investment must be higher than in the reference scenario. The increase of energy efficiency and the wide development of RES lead to higher investment expenditures, as consumers shift towards buying more efficient energy products, equipment, appliances, and vehicles. The investment expenditures across policy scenarios are higher in scenarios with more ambitious energy efficiency targets, i.e., DCarb1. Policy scenarios with the most ambitious RES share (i.e., DCarb3, DCarb4) are not projected to have investment levels significantly higher compared to the reference scenario (*Figure 42*). Overall, there is a shift from consumption to investment expenditure.

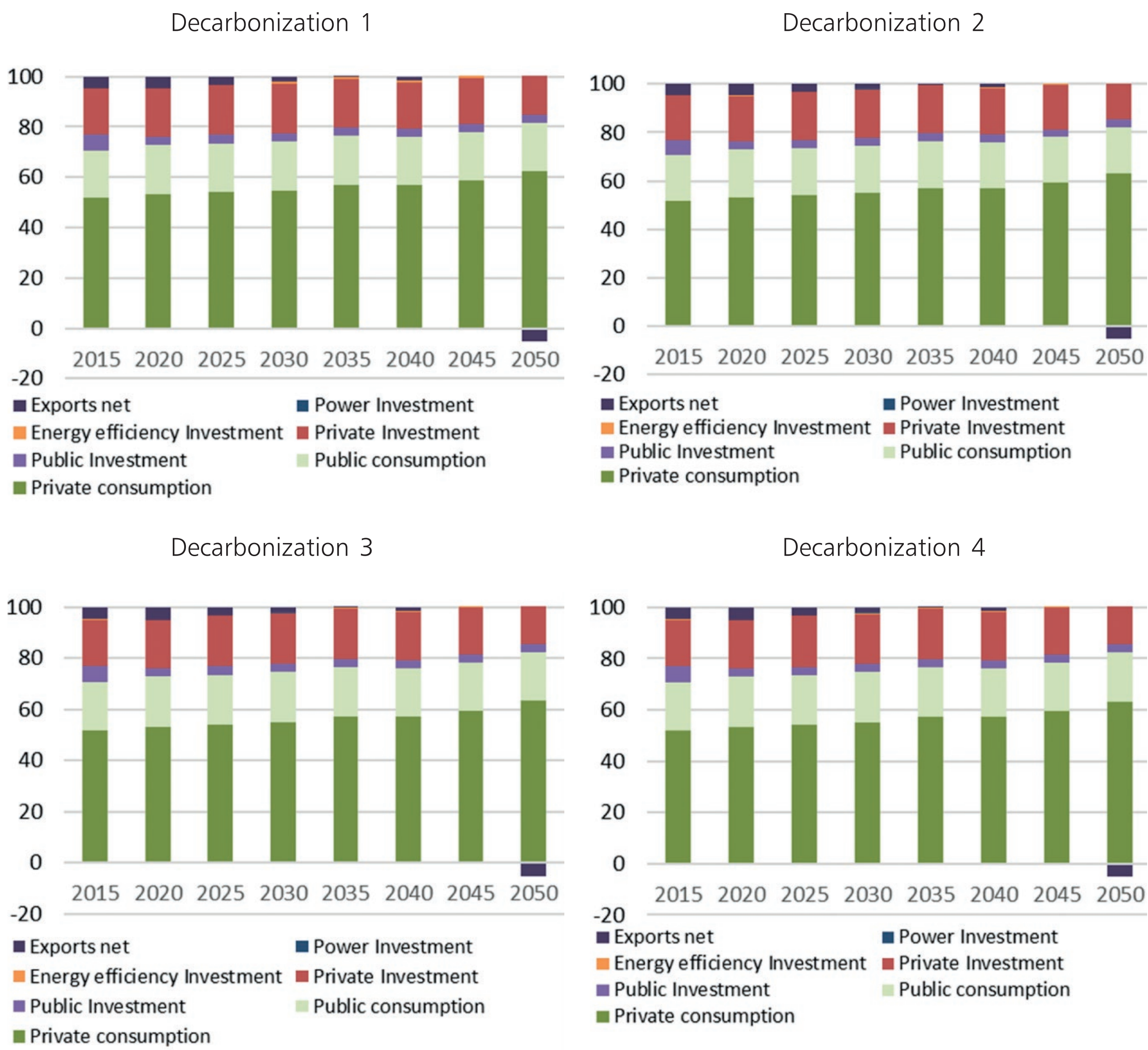
Figure 42. Energy efficiency investments by sector, by scenario, 2011 to 2050, in € billions
Investment in energy efficiency by both households and businesses jumps after 2030



Source: E3-Modelling, CPS Technical Report.

As noted earlier, the analysis finds positive impacts on GDP, especially over the longer term, and that the drop in consumption is driven to a great extent by emission mitigation policies outside of Slovakia. The pattern of GDP follows the size of investment in energy efficiency, with higher investments in energy efficiency leading to lower consumption but higher GDP in total. This impact is driven by crowding out of private investment as a result of higher investments in energy efficiency. Lower private investment erodes the economy's capital stock, leading to lower output. All four scenarios involve a reduction of consumption (of three to six percent compared to the reference scenario during 2040-2050). Household consumption is lower as households reduce consumption to pay for investments in efficiency, particularly building improvements. Investments in energy efficiency increases. Investment in power generation increases towards the end of the period as Slovakia builds a new nuclear generation plant. Exports contract both due to a loss in competitiveness as the cost of efficiency investments are passed on to consumers and due to lower productive capacity of the economy from the lower capital stock. Importantly, the macroeconomic impact on Slovakia is caused not only by its domestic policies but more than half of the consumption decline is caused by decarbonization policies in the rest of the EU (which is modeled as a carbon tax in both ETS and non-ETS sectors). Policies in the rest of the EU lead to lower imports from Slovakia. For example, only about 50 to 60 percent of the drop in consumption in Slovakia during 2040 to 2050 is due to domestic policies (including ETS emissions pricing in Slovakia), while the rest is due to lower demand from the rest of the EU driven by a deterioration in the terms-of-trade (*Figure 28*, *Figure 43*).

Figure 43. Expenditure shares in GDP, by policy scenario, 2015-2050, in %
The economy shifts away from consumption to fund investments in energy efficiency



Source: Slovak-CGE model results.

Photo: Night Cityscape, Bratislava [https://www.goodfreephotos.com]

CHAPTER 5

A LOW CARBON GROWTH PATH: RECOMMENDA-TIONS

This chapter sets out a summary of the main elements of a low carbon growth path for Slovakia, based on the analysis of this study. It also offers a few strategic conclusions for policymakers that can aid in design of a national low-carbon growth strategy, drawing on the gaps, uncertainties, and tradeoffs identified during the analysis as well as the findings themselves.

A GROWTH PATH TO 2050 WHILE LOWERING EMISSIONS

The scenarios generated by the CPS and Slovak-CGE models show Slovakia achieving its mitigation targets rather easily. The large use of hydro resources and biomass are behind the easy achievement of the renewables target, whereas gross energy consumption grows very moderately in Slovakia due to the energy efficiency progress achieved in parallel, manifested by an improvement of the energy intensity of GDP. Despite the lack of additional policies supporting the use of renewables, the renewables share follows an ascending trend over time due to the rising EU ETS carbon prices. The ETS carbon prices affects the power sector, as well as the energy intensive industries and constitutes the main driver for the carbon emission reduction.

The reference scenario projects energy-related CO_2 emissions to decrease. Energy emissions fall by 1 percent and 11 percent in 2030 and 2050, correspondingly, compared to the 2015 levels. This is mainly achieved by the CO_2 emission reduction of the ETS sectors, the power sector and the energy intensive industries. The power sector, being subject to ETS, decarbonizes significantly mainly due to the commissioning of new nuclear reactors and the moderate development of renewables. Thus, power sector emissions are 19 percent lower in 2050 compared to 2015 levels. The industrial sectors also decarbonize, reducing emissions by 24 percent in 2050 compared to 2015, due to efficiency improvements and changes in the fuel mix in energy intensive industries.

In the reference scenario, non-ETS sectors, by comparison, do not face a carbon price, and no energy efficiency and other policies beyond 2020 are assumed. Nonetheless, the long-lasting effects of energy efficiency policies focusing on 2020, the eco-design and car standards, and the market-driven energy productivity improvements sustain a downward trend in carbon emissions in the non-ETS sectors over the medium-term, mainly until 2035. In the longer term, the absence of additional policies in the reference scenario and sustained economic growth pace outrun the technical efficiency progress of new equipment, causing CO2 emissions to trend up from 2040 onwards in the non-ETS sectors.

Looking across the policy scenarios, all exhibit the same effort towards reducing CO_2 emissions overtime. The CO_2 emissions in Slovakia decrease by 65 percent in 2050, compared to 2015 levels, whereas in the reference scenario the emissions decrease by only 11 percent. By 2030, the CO_2 emissions decrease by 18 percent compared to 2015. The variation is small across the policy scenarios, by assumption. In fact, a less ambitious RES target combines with a more ambitious efficiency target, and *vice versa* in the definitions of the policy scenarios.

The EU ETS price trajectory drives the emissions reduction in the ETS sectors, which represent the largest part of total CO_2 emissions. The introduction of a new nuclear reactor and the deployment of renewables enable the decarbonization of the power sector, which plays a significant role in the ETS emission reduction. In the non-ETS sectors, the main drivers of the emission reduction are the energy efficiency policies, the technology standards and additional policies related to the transport sector (vehicle standards). The efficiency policies from a national perspective will have to focus mainly on facilitating the renovation of buildings over the entire projection period. The promotion of heat pumps and new uses of electricity drive accelerated electrification, which is more intense in the long-term due to electrification of road transport. The increase of the ambition of the policy scenarios regarding renewables implies varied penetration of renewables in the power sector and in the heating sector but do not vary in the transport sector.

The policy scenarios were designed to provide a contrasting mix of targets, to assess the impacts of setting different ambitions for the renewables and energy efficiency targets. Setting renewables (RES) and the energy efficiency (EE) targets is at the discretion of national policy. The suggested range for the RES-share in 2030 is 16.5 to 22 percent. The baseline scenario projects 14 percent for the RES-share in 2030. The suggested range for the energy efficiency target in 2030 is -30 to -29 percent. The reference scenario projects -25 percent for the energy efficiency target in 2030. From these numbers alone, it would be presumed that Slovakia needs a considerable effort to achieve both RES and EE targets in 2030, above the business-as-usual trends reflected in the reference scenario projection.

The range of possibilities is larger for the RES target than for the EE target. For the latter, the most important policy focus must regard the renovation of buildings, which constitute the most important source of possible energy savings until 2030. The potential of savings in industry and transport, which are very significant, can only be deployed in the longer-term. For renewables, there exists a trade-off between developing biomass or variable-RES in the power sector. However, both are needed to develop significantly if the RES-share target is ambitious. Achieving energy efficiency targets by 2030 requires significant effort in renovation of buildings.

The main outcomes in the scenarios can be summarized:

(i) Decarbonization of electricity generation is achieved through additional investment in nuclear generation and renewables.

(ii) More stringent efficiency policies drive down final energy demand in all demand sectors, except transport

(iii) The industry and transport sectors are the most significant among the demand sectors in terms of total energy savings, representing 60-80 percent of total energy savings across policy scenarios

(iv) For the transport sector, the additional policies introduced across the policy scenarios are the same; thus, transport demand is similar across policy scenarios. Emissions standards for cars and vans and efficiency standards for trucks, along with the electrification of transport and the increased use of biofuels, enable a significant reduction of energy demand in the transport sector. However, any decarbonization scenario for Slovakia requires electrification of the transport sector in the long-term.

(v) In the industrial sector, the reduction in energy demand increases as more ambitious efficiency policies are implemented, with rising energy efficiency during 2025-2035. After 2035, the energy savings of industry is not significantly different across scenarios, indicating that it is the rising EU ETS price that is the main driver of investment in more efficient technologies.

(vi) Funding these investments will lead to a reduction in household consumption but create opportunities in industries supplying investment goods such as construction.

STRATEGIC CONCLUSIONS FOR POLICYMAKERS

The analysis undertaken via modelling of the macroeconomy and the energy sector as well as other investigation identified possible low carbon growth paths for Slovakia but also identified issues that merit strategic consideration by policymakers. These issues are likely to include: gaps in data and knowledge, uncertainties such as the speed of technological change and future global and regional developments, and a variety of tradeoffs related to the costs of mitigation actions, implementation difficulty, timing, and many others. The energy and macroeconomic models should serve as valuable tools for ongoing assessment of mitigation options for Slovakia.

The newly-adopted EU targets of 32 percent for renewables and 32.5 percent for energy efficiency in 2030 are higher than assumed in this analysis. After the completion of this analysis, the European Union finally adopted targets of 32 percent and 32.5 percent for RES and EE respectively. Obviously, these are higher than the targets assumed in the Slovakian policy scenarios explored in this study. Most likely, the new EU targets imply that Slovakia will be obliged to adopt ambitious targets for both RES and EE, for example 22 percent for RES and 30 percent for energy efficiency. The findings of the analysis presented here suggests that both biomass and variable renewables will have to develop, accompanied by the strongest possible policy promoting renovation of buildings to the horizon of 2030.

Photo: Slovakia Bojnice, photo by Aleksandr Markin (https://www.flickr.com/photos/33104187@N04/8698340484)

ANNEX 1

A NON-TECHNICAL EXPLANATION OF THE DECARBONIZATION SCENARIOS

A scenario approach is used to assess alternative settings of targets related to Slovakia's national strategy for climate mitigation. The choice of the mix of targets is not simplistically the result of cost minimization since the best choice also depends on non-economic criteria. Security of energy supply, implementation feasibility, political constraints, social acceptance, and economic affordability for more vulnerable economic classes are among the criteria to consider in addition to system cost minimization. The modelling is able to quantify performance on some of these criteria in addition to costs, such as energy dependence on imports, system reliability, and consumer tariffs. The modelling is able to include implementation difficulties, social acceptance, and other restrictions on the cost-potential curves of resources, such as nuclear siting or renewable resource availability. A full accounting of performance against multiple criteria can be handled practically by quantifying alternative policy scenarios (which contain alternative targets).

The policy scenarios were designed as contrasting and stylized mixes of targets, to assess the impacts of setting different ambitions for Slovakia's renewable energy (RES) and energy efficiency (EE) targets. Setting the renewables and the energy efficiency targets is at the discretion of the national policy. For a national plan to be acceptable to the EU, it is necessary that low ambition on one target is compensated by high ambition on the other target. The modelling takes into account synergies between the targets, since energy efficiency (e.g., heat pumps) may also enable higher renewables and vice-versa. In addition, high performance in energy efficiency reduces energy consumption, which reduces the denominator of the RES-shares, facilitating the achievement of higher RES targets. Despite the complementarities taken into account in the modelling, the two targets require very different policy frameworks, and in this way, the targets conflict with each other from a policy implementation perspective. Some of the efficiency-enabling policies, such as car standards and eco-design regulations, are not at the discretion of national government and instead result from Europe-wide decision-making. Nevertheless, policies supporting efficiency in buildings, some transport policies, and support schemes for RES, heat pumps and other technologies and fuels, including biomass, are subject to national jurisdiction. The ETS carbon price is determined at a pan-European level, and Slovakia is a price-taker from this market. National performance in the non-ETS sectors, which is subject to a national target different for each EU member, derives from the choice of targets for energy efficiency and renewables and the ambition of non-CO_2 GHG emissions reduction.

Four policy scenarios are assessed and compared against a reference scenario (with no new policies). The policy scenarios can be simplified as: (i) a low energy efficiency and high RES scenario; (ii) a high target for energy efficiency and low RES scenario; (iii) a middle case scenario; and, (iv) a scenario with very ambitious RES (mainly renewables in electricity generation) and less energy efficiency (*Table 8*).

Table 8. Decarbonization scenarios by renewables and energy efficiency target intensity

A simplified view of the decarbonization scenarios

Scenario Name	Renewables target	Energy efficiency target
Decarbonization 1	Basic	Ambitious
Decarbonization 2	Median	Median
Decarbonization 3	Ambitious	Basic
Decarbonization 4	Very ambitious (for electricity)	Basic

Source: E3-Modelling, CPS Technical Report.

ANNEX 2

EU POLICIES AND NATIONAL MEASURES IMPLEMENTING EU POLICIES

A number of policies defined at the EU level are needed to achieve the EU's 2030 targets and are assumed as part of the scenarios analyzed here. The main such policies are:

(i) ETS: Increase of the ETS carbon prices enabled by the Market Stability Reserve, assumed to apply without exemptions, except the leakage regulations for industry. It is exogenous in all policy scenarios, taken from the EUCO scenarios (see footnote 17).

(ii) Renewables: Renewables support policies in various sectors expressed by rising the shadow value of RES in the electricity model, in the heating sector and in transport regarding the biofuels. The RES value is the shadow value of an implicit minimum contribution of renewables per sector, which influences decision-making of agents as a marginal benefit of using renewables (per unit of energy). The scenarios assume different RES-values per sector to represent different policy priorities of renewables development in the sectors.

(iii) Energy efficiency: Emphasis on policies supporting faster renovation of old buildings compared to historic trends and deep energy insulations in the renovated buildings. The model represents such policies by rising the energy efficiency value, which stands for the shadow value of a virtual constraint on energy savings in the heating of buildings, and acts in the model as a marginal benefit per unit of energy consumed due to energy savings. The energy efficiency policies also include strict building codes for new constructions, the promotion of heat recovery and best available techniques in industry, infrastructure and soft measures enabling higher efficiency in the transport sector and the EU-wide measures that include car standards and eco-design regulations.

(iv) Transport policies: The main policy measures are not at the discretion of national policies, such as the CO2 car standards (70-75 gCO2/km in 2030, 25 in 2050) and for Vans (120 in 230, 60 in 2050), the efficiency standards (1.5% increase per year) for trucks. However, infrastructure and other transport policies improving the efficiency of transportation in cities and the logistics are at the discretion of national policies.

(v) Enabling conditions: The scenarios assume a reduction of uncertainty and consequently a decrease in received costs for new technologies and efficient appliances, accompanied by a removal of barriers to investment in house renovation and other similar actions in various sectors, which otherwise influence decision-making as hidden costs. The removal of barriers also imply a reduction of discount rates used in the decision of capital-intensive energy efficient equipment and investment. Finally, the scenarios involve new infrastructure facilitating charging of electric vehicles, smart systems, grids facilitating development of renewables, higher learning rates of new and advanced technologies (that take place at a pan – European level), and positive anticipation of the rising ETS prices in the future.

Complementary national policies will also be needed for the policy scenarios. In addition to the national policies included in the Slovak reference scenario, the policy scenarios include the following national policies:

(i) Earlier decommissioning of solid-fired utility power plants: Vojany and Novaky power plants are assumed to decommission in 2025 and 2023 respectively.

(ii) RES support scheme in power generation: Eligible RES technologies are Solar PV, wind onshore turbines and biomass. The scenarios assume a support to 50MW in the period 2021-2025, followed by the support of another 500MW based on auctions.

(iii) Further development of nuclear energy is possible based on economic optimality

(iv) Carbon capture and storage is excluded.

ANNEX 3

DETAILED OUTCOMES BY DECARBONIZATION POLICY SCENARIO FROM THE SLOVAK-CGE MODEL

Table 9. Value added, Decarbonization 1 scenario, by sector, 2015-2050, in % change in constant 2011 billion USD from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,2	0,6	1,6	3,4	3,8	4,1
Livestock	0,0	0,0	0,2	-0,3	0,3	0,4	0,8	1,2
Coal	-0,3	1,3	-10,9	-11,8	0,4	-7,7	-18,5	-8,4
Oil	0,0	0,0	-1,5	-3,1	-11,0	-18,5	-28,6	-45,8
Gas extraction and distribution	-0,1	0,5	-2,0	-7,9	-41,9	-60,3	-80,3	-96,6
Other Mining	0,0	0,2	0,3	2,6	2,2	2,5	2,8	2,5
Food, Beverage and Tobacco	0,0	0,0	0,0	-0,8	0,2	-0,4	-0,7	-0,3
Textiles and Clothing	0,0	-0,1	0,1	-0,4	1,1	5,9	8,5	9,4
Wood products	0,0	0,0	-0,1	-0,1	1,9	8,1	11,0	15,9
Paper products, publishing	-0,1	0,6	1,0	1,0	5,9	8,9	8,0	26,6
Petroleum, coal products	0,0	0,1	-2,2	-4,0	-12,4	-21,9	-31,9	-44,0
Chemical, rubber, plastic products	-0,1	0,4	0,0	4,0	1,6	0,4	-7,7	-19,5
Mineral products n.e.s.	0,0	0,0	0,3	1,0	2,9	5,5	7,4	11,7
Iron and Steel	-0,1	0,4	1,1	3,2	0,8	-4,1	-12,6	-27,7
Non-ferrous metals	-0,1	0,6	-1,0	7,4	8,3	15,7	36,3	62,4
Fabricated metal products	0,0	-0,1	-0,3	-0,7	0,7	8,3	10,7	8,3
Motor vehicles and parts	0,0	0,0	-0,4	-1,0	-0,7	2,2	2,9	1,0
Transport equipment n.e.s.	0,0	-0,1	-0,4	-1,4	-1,4	2,4	4,3	1,8
Electronic equipment	0,0	-0,1	1,7	2,4	3,8	9,1	11,2	8,9
Machinery and equipment n.e.s.	0,0	-0,1	-0,2	-0,8	0,0	5,3	7,5	7,4
Manufactures n.e.s.	0,0	0,0	-0,2	-0,8	-0,2	2,5	3,2	2,5
Electricity transmission and distribution	0,0	0,1	-1,9	-3,8	-6,3	-8,0	-9,7	-5,9
Nuclear power	0,0	0,1	-0,6	1,0	0,3	-2,7	-6,1	46,2
Coal power	0,0	0,0	-54,8	-74,7	767,5	17,6	-9,7	-5,9
Gas power	0,0	0,0	19,5	-2,6	-33,2	-47,8	-55,5	-92,3
Wind power	0,0	0,1	-1,9	1,0	0,3	55,9	183,7	337,6
Hydro power	0,0	0,1	-0,6	1,0	0,3	0,6	5,6	-13,2
Oil power	0,0	0,1	-1,9	-3,8	-6,3	-8,0	-9,7	-5,9
Other power	0,0	0,1	-10,5	32,0	16,5	170,4	190,9	172,8
Solar power	0,0	0,1	-0,6	1,0	163,8	145,2	139,0	119,5
Water	0,0	0,0	-0,1	-1,0	-1,2	-5,0	-6,9	-8,2
Construction	0,0	0,0	0,3	4,6	2,4	1,1	1,9	5,9
Trade	0,0	0,0	0,0	-0,4	-0,5	-2,7	-4,2	-5,6
Transport n.e.s.	0,0	0,0	0,2	-0,3	0,4	-6,9	-9,2	-10,0
Sea transport	0,0	0,0	0,7	1,6	2,9	-0,6	-0,3	-2,1
Air transport	0,0	-0,1	0,1	-0,3	-3,4	-6,2	-10,7	-24,3
Market Services	0,0	0,0	-0,1	-0,9	-1,1	-3,2	-4,7	-6,3
Non-market Services	0,0	0,0	0,0	-0,2	-0,2	-0,9	-1,3	-1,8
Dwellings	0,0	0,0	-0,1	-1,5	-2,1	-7,5	-10,3	-12,2

Table 10. Value added, Decarbonization 2 scenario, by sector, 2015-2050, in % change in constant 2011 billion USD from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,8	3,9	5,5	6,2	6,5	6,2
Livestock	0,0	0,0	-0,1	-0,9	-0,4	0,5	1,1	1,8
Coal	1,0	0,6	-11,5	-13,8	5,7	-7,6	-19,5	-8,0
Oil	0,1	-0,1	0,1	-2,9	-10,1	-17,9	-28,0	-45,4
Gas extraction and distribution	0,5	0,3	-4,9	-12,5	-43,6	-60,5	-80,0	-96,5
Other Mining	0,2	0,1	0,0	1,6	2,3	1,8	2,9	3,5
Food, Beverage and Tobacco	0,0	0,0	-0,3	-1,1	-0,6	-0,8	-0,9	0,0
Textiles and Clothing	0,0	0,0	0,2	-0,1	0,7	6,0	8,6	9,3
Wood products	0,0	0,0	-0,4	-1,8	-0,1	6,8	9,5	14,5
Paper products, publishing	0,5	0,4	-1,8	2,6	12,3	16,2	16,8	36,7
Petroleum, coal products	0,1	-0,1	-0,3	-4,2	-11,6	-21,5	-31,5	-43,5
Chemical, rubber, plastic products	0,3	0,2	-0,9	2,2	3,4	0,2	-7,6	-18,1
Mineral products n.e.s.	0,0	0,0	0,2	1,3	3,9	6,5	8,6	13,3
Iron and Steel	0,3	0,2	0,5	1,5	0,2	-6,3	-12,4	-23,7
Non-ferrous metals	0,5	0,3	-1,4	6,1	10,7	15,7	37,0	64,7
Fabricated metal products	0,0	0,0	0,0	-0,4	0,5	8,3	10,7	8,1
Motor vehicles and parts	0,0	0,0	-0,2	-0,7	-0,7	2,4	3,1	0,9
Transport equipment n.e.s.	-0,1	-0,1	0,0	-0,9	-1,8	2,4	4,5	1,9
Electronic equipment	-0,1	0,0	2,1	2,9	3,8	9,7	11,8	9,2
Machinery and equipment n.e.s.	0,0	0,0	0,1	-0,2	-0,2	5,5	7,7	7,4
Manufactures n.e.s.	0,0	0,0	-0,1	-0,7	-0,3	2,6	3,4	2,7
Electricity transmission and distribution	0,1	0,0	-1,5	-3,2	-4,3	-6,0	-7,7	-3,7
Nuclear power	0,1	0,1	-1,0	0,6	-0,3	-3,6	-6,7	47,4
Coal power	0,3	-0,1	-38,7	-92,9	-54,3	16,6	-7,7	-3,7
Gas power	-0,2	-0,1	3,6	-25,2	-50,3	-50,8	-56,0	-92,5
Wind power	0,1	0,0	315,3	86,3	-16,5	-19,1	-21,7	344,2
Hydro power	0,1	0,1	-0,6	1,1	2,5	-0,3	4,8	-12,4
Oil power	0,1	0,0	-1,5	-3,2	-4,3	-6,0	-7,7	-3,7
Other power	0,1	0,1	30,9	200,1	235,9	295,5	321,5	222,8
Solar power	0,1	0,1	-1,0	0,6	54,7	74,5	121,1	89,4
Water	0,0	0,0	-0,1	-0,8	-1,3	-4,8	-6,4	-7,3
Construction	0,0	0,0	-0,4	1,1	0,3	-1,1	-1,1	1,3
Trade	0,0	0,0	0,0	-0,3	-0,5	-2,6	-3,9	-5,1
Transport n.e.s.	0,0	0,0	0,2	-0,1	0,2	-7,0	-9,2	-9,5
Sea transport	0,0	0,0	1,0	1,5	2,5	-0,7	-0,2	-1,7
Air transport	0,0	0,0	0,2	0,0	-3,3	-6,1	-10,6	-24,2
Market Services	0,0	0,0	-0,1	-0,6	-1,0	-2,8	-4,2	-5,5
Non-market Services	0,0	0,0	0,0	-0,1	-0,2	-0,8	-1,1	-1,5
Dwellings	0,0	0,0	-0,3	-1,3	-1,8	-7,0	-9,3	-10,7

Table 11. Value added, Decarbonization 3 scenario, by sector, 2015-2050, in % change in constant 2011 billion USD from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,3	4,7	6,1	6,9	7,1	6,7
Livestock	0,0	0,0	0,2	-1,3	-0,4	0,4	1,1	2,0
Coal	1,7	-2,2	-13,3	-12,9	9,6	-7,4	-22,0	-3,7
Oil	0,1	-0,1	0,2	-2,7	-9,9	-17,8	-28,1	-45,1
Gas extraction and distribution	0,9	-0,8	-4,2	-11,5	-42,4	-59,6	-79,6	-96,3
Other Mining	0,3	-0,3	-0,2	1,1	2,3	1,4	2,1	4,1
Food, Beverage and Tobacco	0,0	0,0	-0,1	-1,4	-0,7	-0,9	-1,0	0,1
Textiles and Clothing	0,0	0,1	0,3	0,2	0,8	6,3	8,9	9,4
Wood products	0,0	0,0	-0,2	-2,0	-0,2	6,5	9,1	14,3
Paper products, publishing	0,9	-1,0	-2,5	0,0	12,4	16,0	17,9	41,1
Petroleum, coal products	0,2	-0,3	-0,2	-4,4	-11,5	-21,7	-31,8	-43,3
Chemical, rubber, plastic products	0,6	-0,7	-1,3	1,4	3,7	-0,5	-8,7	-17,8
Mineral products n.e.s.	0,1	-0,1	0,1	1,1	4,0	6,6	8,6	13,8
Iron and Steel	0,5	-0,5	0,2	0,5	-0,1	-7,6	-13,9	-21,3
Non-ferrous metals	0,9	-1,0	-1,9	4,6	10,7	14,9	35,6	65,0
Fabricated metal products	0,0	0,1	0,1	0,0	0,6	8,6	11,0	8,0
Motor vehicles and parts	0,0	0,0	-0,2	-0,5	-0,6	2,6	3,2	0,9
Transport equipment n.e.s.	-0,1	0,1	0,1	-0,5	-1,8	2,7	4,9	2,0
Electronic equipment	-0,1	0,1	2,2	3,2	3,8	10,0	12,2	9,1
Machinery and equipment n.e.s.	-0,1	0,1	0,2	0,1	-0,1	5,7	8,0	7,6
Manufactures n.e.s.	0,0	0,0	-0,1	-0,5	-0,3	2,7	3,5	2,8
Electricity transmission and distribution	0,2	-0,3	-1,6	-2,1	-3,1	-4,7	-6,5	-1,9
Nuclear power	0,2	-0,3	-1,0	0,1	-0,7	-4,4	-7,8	46,2
Coal power	0,3	-0,1	-44,0	-92,9	-54,5	15,5	-6,5	-1,9
Gas power	0,1	-0,4	13,3	-31,5	-51,7	-51,1	-55,0	-88,8
Wind power	0,2	-0,3	291,4	74,6	-21,6	-24,5	-27,1	340,8
Hydro power	0,2	-0,3	-0,6	3,0	7,1	5,6	3,7	-13,2
Oil power	0,2	-0,3	-1,6	-2,1	-3,1	-4,7	-6,5	-1,9
Other power	0,2	-0,3	-1,4	261,8	267,9	332,2	359,7	235,1
Solar power	0,2	-0,3	-1,0	0,1	39,8	54,8	114,6	85,4
Water	-0,1	0,1	0,0	-0,9	-1,4	-4,8	-6,3	-7,1
Construction	0,0	0,1	-0,4	0,2	-0,3	-1,9	-2,3	-0,6
Trade	0,0	0,0	0,0	-0,4	-0,6	-2,7	-3,9	-5,0
Transport n.e.s.	0,0	0,0	0,3	-0,2	0,1	-7,0	-9,3	-9,4
Sea transport	0,0	0,0	1,0	1,4	2,4	-0,7	-0,5	-1,5
Air transport	-0,1	0,1	0,3	0,2	-3,3	-5,9	-10,5	-24,2
Market Services	0,0	0,0	0,0	-0,6	-1,0	-2,8	-4,0	-5,3
Non-market Services	0,0	0,0	0,0	-0,1	-0,3	-0,8	-1,0	-1,4
Dwellings	0,0	0,0	-0,2	-1,4	-1,9	-6,9	-9,0	-10,1

Table 12. Value added, Decarbonization 4 scenario, by sector, 2015-2050, in % change in constant 2011 billion USD from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,3	4,7	6,1	6,9	7,1	6,7
Livestock	0,0	0,0	0,2	-0,2	0,3	1,3	2,0	2,1
Coal	1,5	-1,3	-13,3	3,2	20,1	9,9	12,5	-9,1
Oil	0,1	-0,1	-0,5	-2,9	-9,8	-17,3	-26,5	-45,2
Gas extraction and distribution	0,7	-0,5	-4,7	-9,7	-41,9	-59,1	-78,3	-96,3
Other Mining	0,3	-0,2	-0,4	1,9	2,0	2,4	5,6	3,1
Food, Beverage and Tobacco	0,0	0,0	-0,1	-0,7	0,1	0,3	0,7	0,8
Textiles and Clothing	0,0	0,0	0,2	-0,9	0,3	5,9	8,2	10,0
Wood products	0,0	0,0	-0,3	-1,5	0,9	8,4	12,2	16,0
Paper products, publishing	0,7	-0,7	-2,8	8,1	16,4	23,0	30,9	38,9
Petroleum, coal products	0,1	-0,2	-1,1	-3,3	-11,1	-20,6	-29,3	-43,5
Chemical, rubber, plastic products	0,5	-0,4	-1,5	5,3	5,2	3,5	-0,5	-18,2
Mineral products n.e.s.	0,1	0,0	0,1	0,9	3,8	7,1	10,8	13,8
Iron and Steel	0,4	-0,3	0,0	4,2	1,5	-4,5	-7,2	-23,2
Non-ferrous metals	0,7	-0,6	-2,3	4,0	6,7	15,5	43,9	59,7
Fabricated metal products	0,0	0,1	0,0	-2,1	-0,6	7,3	9,6	9,5
Motor vehicles and parts	0,0	0,0	-0,2	-1,6	-1,2	1,8	2,4	1,5
Transport equipment n.e.s.	-0,1	0,1	0,0	-2,8	-3,0	1,3	2,8	1,3
Electronic equipment	-0,1	0,1	2,2	1,0	2,7	8,2	9,5	10,2
Machinery and equipment n.e.s.	0,0	0,1	0,1	-1,5	-1,0	4,8	6,5	7,0
Manufactures n.e.s.	0,0	0,0	-0,1	-1,3	-0,6	2,5	3,4	3,3
Electricity transmission and distribution	0,2	-0,2	-1,7	-0,8	-2,3	-4,0	-4,8	-2,6
Nuclear power	0,2	-0,2	-1,1	0,7	-0,9	-4,1	-7,1	45,5
Coal power	0,4	-0,1	-40,2	-97,2	-0,9	15,9	-4,8	-2,6
Gas power	-0,1	-0,2	8,2	-47,8	-63,4	-67,5	-70,3	-89,0
Wind power	0,2	-0,2	386,2	1491,8	429,4	507,3	568,5	491,8
Hydro power	0,2	-0,2	-0,7	8,9	7,2	3,6	4,4	-13,6
Oil power	0,2	-0,2	-1,7	-0,8	-2,3	-3,9	-4,8	-2,6
Other power	0,2	-0,2	2,9	141,4	136,8	166,1	190,7	153,1
Solar power	0,2	-0,2	37,3	411,5	543,6	555,7	498,9	140,5
Water	0,0	0,0	0,0	-1,1	-1,3	-4,6	-6,1	-6,6
Construction	0,0	0,1	-0,4	0,9	0,0	-1,4	-1,8	-0,8
Trade	0,0	0,0	0,0	-0,7	-0,7	-2,6	-3,7	-4,7
Transport n.e.s.	0,0	0,0	0,3	-0,8	-0,1	-7,4	-9,7	-9,1
Sea transport	0,0	0,0	1,0	0,6	2,0	-0,5	-0,9	-1,5
Air transport	0,0	0,0	0,3	-0,6	-3,7	-6,3	-11,1	-24,2
Market Services	0,0	0,0	0,0	-1,2	-1,2	-2,8	-4,0	-4,8
Non-market Services	0,0	0,0	0,0	-0,2	-0,3	-0,8	-1,1	-1,3
Dwellings	0,0	0,0	-0,1	-1,6	-1,8	-6,3	-8,2	-9,6

Table 13. Emissions, Decarbonization 1 scenario, by sector, 2015-2050, in % change in $MtCO_2$ from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	-0,3	-1,8	-1,2	0,5	0,2	0,1
Livestock	0,0	0,0	0,3	-1,0	-0,5	0,0	0,4	0,3
Coal	-0,3	1,3	-10,9	-11,9	0,2	-7,9	-18,8	-8,7
Oil	0,0	0,0	-1,6	-3,2	-11,2	-18,8	-29,2	-47,1
Gas extraction and distribution	-0,1	0,5	-2,0	-7,9	-42,0	-60,3	-80,3	-96,7
Other Mining	0,0	0,2	-1,4	-1,5	3,6	11,5	20,2	27,7
Food, Beverage and Tobacco	0,0	0,0	-1,5	-2,0	17,0	41,9	64,5	81,6
Textiles and Clothing	0,0	0,0	1,5	-3,1	5,1	13,2	16,7	22,8
Wood products	0,0	0,0	-1,2	-2,5	10,5	28,9	45,9	66,9
Paper products, publishing	-0,1	0,7	7,6	-3,4	16,4	26,5	10,3	-30,1
Petroleum, coal products	0,0	0,1	-2,2	-4,0	-12,4	-21,9	-31,9	-44,0
Chemical, rubber, plastic products	-0,1	0,4	-0,1	3,5	1,5	0,7	-7,4	-19,8
Mineral products n.e.s.	0,0	0,1	0,9	-19,8	-23,8	-30,1	-44,9	-63,3
Iron and Steel	-0,1	0,4	1,7	-7,2	-13,1	-25,8	-42,7	-70,1
Non-ferrous metals	-0,1	0,7	-4,1	-0,5	-5,7	-9,0	-9,3	-3,5
Fabricated metal products	0,0	0,0	-0,3	-7,8	-3,0	7,1	11,3	8,8
Motor vehicles and parts	0,0	0,0	-0,5	-7,9	-4,4	0,8	3,1	0,8
Transport equipment n.e.s.	0,0	-0,1	-0,5	-7,8	-4,8	1,2	4,9	2,1
Electronic equipment	0,0	-0,1	1,8	0,4	2,9	8,9	11,5	9,3
Machinery and equipment n.e.s.	0,0	-0,1	-0,2	-7,8	-3,6	4,4	8,4	8,2
Manufactures n.e.s.	0,0	0,0	-1,4	-3,5	7,1	20,6	33,5	44,9
Electricity transmission and distribution	0,0	-1,5	-70,0	-66,0	-66,9	-67,5	-68,1	-66,7
Nuclear power								
Coal power	0,0	0,1	-65,0	-98,3	-89,9	-98,6	-99,0	-98,9
Gas power	0,0	-0,1	1,0	-12,0	-33,4	-47,5	-55,5	-93,5
Wind power								
Hydro power								
Oil power	0,0	-1,5	-70,0	-66,0	-66,9	-67,5	-68,1	-66,7
Other power	0,0	-1,5	-72,6	-53,3	-58,8	-4,4	2,9	-3,5
Solar power								
Water	0,0	0,0	-2,2	-19,8	-15,7	-18,6	-21,8	-26,4
Construction	0,0	0,0	0,3	4,7	2,4	1,2	2,0	6,0
Trade	0,0	0,0	-2,8	-18,9	-17,2	-20,5	-24,9	-30,0
Transport n.e.s.	0,0	0,0	-2,8	-8,1	-19,5	-30,8	-42,6	-53,6
Sea transport	0,0	0,0	0,7	1,6	3,0	-0,7	-0,4	-2,2
Air transport	0,0	0,0	0,1	-0,3	-3,6	-6,6	-11,2	-24,7
Market Services	0,0	0,0	-1,9	-18,6	-15,1	-16,9	-21,4	-27,1
Non-market Services	0,0	0,0	-0,4	-3,4	-2,6	-3,0	-3,5	-4,1
Dwellings	0,0	0,0	-2,9	-19,5	-18,5	-24,5	-29,9	-35,3
Households	0,0	0,0	-3,7	-8,1	-21,3	-37,9	-47,4	-51,6

Table 14. Emissions, Decarbonization 2 scenario, by sector, 2015-2050, in % change in $MtCO_2$ from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,5	1,9	2,7	3,1	2,9	2,1
Livestock	0,0	0,0	0,1	-0,8	0,0	1,9	2,5	2,8
Coal	1,0	0,6	-11,6	-13,9	5,6	-7,7	-19,7	-8,4
Oil	0,1	-0,1	0,1	-2,9	-10,3	-18,2	-28,6	-46,7
Gas extraction and distribution	0,5	0,3	-4,9	-12,5	-43,6	-60,6	-80,1	-96,5
Other Mining	0,2	0,1	-1,9	-1,9	0,5	7,1	16,3	26,1
Food, Beverage and Tobacco	0,0	0,0	-1,7	0,4	14,5	37,0	58,7	74,8
Textiles and Clothing	0,0	0,0	0,8	-0,3	4,2	11,3	13,6	17,9
Wood products	0,0	0,0	-1,8	-3,5	4,3	22,5	38,9	61,0
Paper products, publishing	0,5	0,4	5,4	-5,7	8,3	9,0	-4,4	-31,0
Petroleum, coal products	0,1	-0,1	-0,3	-4,2	-11,6	-21,5	-31,5	-43,5
Chemical, rubber, plastic products	0,3	0,2	-1,0	2,0	3,3	0,4	-7,4	-18,4
Mineral products n.e.s.	0,0	0,1	1,4	-17,8	-22,2	-30,6	-45,6	-62,2
Iron and Steel	0,3	0,3	1,3	-7,3	-11,5	-24,6	-42,2	-68,7
Non-ferrous metals	0,5	0,4	-3,4	2,6	-0,3	-7,2	-6,7	0,1
Fabricated metal products	0,0	0,0	0,1	-3,3	-0,9	9,3	13,8	9,8
Motor vehicles and parts	0,0	0,0	-0,3	-3,6	-2,1	2,9	5,4	2,0
Transport equipment n.e.s.	-0,1	0,0	0,0	-3,6	-3,1	3,1	7,0	3,3
Electronic equipment	-0,1	0,0	2,1	2,1	3,6	10,0	12,7	10,0
Machinery and equipment n.e.s.	0,0	0,0	0,1	-3,1	-1,4	6,6	11,0	9,5
Manufactures n.e.s.	0,0	0,0	-1,7	-2,7	3,0	16,1	29,1	41,7
Electricity transmission and distribution	0,4	-3,3	141,1	176,8	173,7	168,8	164,1	175,4
Nuclear power								
Coal power	0,1	0,1	-54,1	-98,4	-94,0	-84,6	-87,8	-87,3
Gas power	-0,1	-0,4	-8,1	-31,1	-51,2	-53,4	-56,6	-93,6
Wind power								
Hydro power								
Oil power	0,4	-3,3	141,1	176,8	173,7	168,9	164,1	175,4
Other power	0,4	-3,3	220,6	758,4	860,6	1031,2	1105,6	823,3
Solar power								
Water	0,0	0,0	-0,4	-10,9	-12,3	-15,6	-17,8	-21,2
Construction	0,0	0,0	-0,4	1,2	0,3	-1,0	-1,0	1,4
Trade	0,0	0,0	-1,1	-12,0	-15,2	-18,5	-21,8	-25,6
Transport n.e.s.	0,0	0,0	-2,8	-8,6	-19,8	-30,8	-42,7	-53,7
Sea transport	0,0	0,0	1,0	1,5	2,5	-0,9	-0,4	-1,8
Air transport	0,0	0,0	0,2	0,0	-3,5	-6,5	-11,1	-24,6
Market Services	0,0	0,0	-0,3	-9,5	-10,9	-13,6	-17,1	-22,2
Non-market Services	0,0	0,0	-0,1	-1,9	-2,1	-2,6	-2,9	-3,4
Dwellings	0,0	0,0	-1,4	-12,7	-16,2	-22,3	-26,7	-30,5
Households	0,0	0,0	-2,9	-10,8	-18,9	-34,5	-44,0	-48,6

Table 15. Emissions, Decarbonization 3 scenario, by sector, 2015-2050, in % change in $MtCO_2$ from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,0	2,8	3,3	4,0	3,7	3,0
Livestock	0,0	0,0	0,3	-1,2	0,1	2,1	2,9	3,4
Coal	1,8	-2,2	-13,3	-13,0	9,5	-7,5	-22,3	-4,0
Oil	0,1	-0,1	0,2	-2,8	-10,1	-18,1	-28,7	-46,4
Gas extraction and distribution	0,9	-0,8	-4,2	-11,6	-42,4	-59,6	-79,7	-96,3
Other Mining	0,3	-0,3	-2,1	-3,7	-1,9	5,1	16,7	27,6
Food, Beverage and Tobacco	0,0	0,1	-1,5	1,8	15,3	36,0	59,9	76,5
Textiles and Clothing	0,0	0,1	0,8	0,0	3,8	10,7	15,0	19,0
Wood products	0,0	0,0	-1,5	-5,2	1,2	20,2	40,0	61,9
Paper products, publishing	0,9	-1,0	4,8	-7,7	5,7	5,0	-5,8	-37,6
Petroleum, coal products	0,2	-0,3	-0,2	-4,4	-11,5	-21,7	-31,8	-43,3
Chemical, rubber, plastic products	0,6	-0,7	-1,4	1,3	3,7	-0,3	-8,4	-18,1
Mineral products n.e.s.	0,1	-0,1	1,5	-15,0	-20,8	-30,6	-45,3	-63,3
Iron and Steel	0,5	-0,4	0,9	-6,6	-10,7	-24,0	-41,8	-67,7
Non-ferrous metals	0,9	-1,1	-3,6	2,3	0,5	-7,3	-7,0	1,0
Fabricated metal products	0,0	0,1	0,1	-2,2	-0,1	10,0	15,6	11,3
Motor vehicles and parts	0,0	0,1	-0,2	-2,7	-1,5	3,5	6,9	3,4
Transport equipment n.e.s.	-0,1	0,1	0,1	-2,5	-2,6	3,8	8,8	4,8
Electronic equipment	-0,1	0,1	2,3	2,7	3,7	10,4	13,6	10,4
Machinery and equipment n.e.s.	-0,1	0,1	0,2	-2,1	-0,7	7,3	12,9	11,3
Manufactures n.e.s.	0,0	0,1	-1,6	-4,1	0,1	14,3	30,6	42,9
Electricity transmission and distribution	0,3	-2,1	139,7	195,4	192,5	187,6	182,3	195,9
Nuclear power								
Coal power	0,2	-0,3	-58,5	-98,4	-94,0	-84,8	-87,7	-87,1
Gas power	0,1	-0,5	-1,9	-36,1	-52,4	-54,8	-56,4	-90,6
Wind power								
Hydro power								
Oil power	0,3	-2,1	139,8	195,4	192,5	187,7	182,3	195,9
Other power	0,3	-2,1	140,4	991,9	1010,3	1204,3	1287,6	911,5
Solar power								
Water	-0,1	0,1	-0,1	-9,7	-10,6	-12,6	-13,0	-14,4
Construction	0,0	0,1	-0,4	0,2	-0,3	-1,9	-2,3	-0,5
Trade	0,0	0,0	-0,9	-11,1	-13,9	-16,0	-17,8	-19,3
Transport n.e.s.	0,0	0,1	-2,7	-8,6	-19,8	-30,8	-42,7	-53,8
Sea transport	0,0	0,0	1,0	1,5	2,5	-0,9	-0,7	-1,7
Air transport	-0,1	0,1	0,3	0,2	-3,5	-6,4	-11,0	-24,6
Market Services	0,0	0,1	0,0	-8,3	-9,1	-10,6	-12,4	-16,0
Non-market Services	0,0	0,0	0,0	-1,7	-1,8	-2,2	-2,3	-2,5
Dwellings	0,0	0,1	-1,1	-11,9	-14,9	-20,0	-22,8	-24,4
Households	0,0	0,0	-2,7	-9,4	-16,9	-31,6	-40,5	-44,9

Table 16. Emissions, Decarbonization 4 scenario, by sector, 2015-2050, in % change in $MtCO_2$ from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,0	0,1	0,5	1,4	1,4	1,4
Livestock	0,0	0,0	0,3	-0,4	0,5	2,5	3,6	3,4
Coal	1,5	-1,4	-13,4	3,1	20,1	9,9	12,5	-9,3
Oil	0,1	-0,1	-0,5	-2,9	-10,1	-17,6	-27,0	-46,5
Gas extraction and distribution	0,7	-0,5	-4,7	-9,7	-41,9	-59,1	-78,3	-96,3
Other Mining	0,2	-0,1	-2,2	0,3	2,4	11,7	25,8	30,2
Food, Beverage and Tobacco	0,0	0,0	-1,6	3,5	17,5	45,8	72,3	85,4
Textiles and Clothing	0,0	0,1	0,6	0,8	5,3	16,7	21,7	25,3
Wood products	0,0	0,0	-1,7	-0,8	8,1	29,6	50,5	69,7
Paper products, publishing	0,7	-0,7	4,4	3,6	16,3	22,5	14,6	-34,2
Petroleum, coal products	0,1	-0,2	-1,1	-3,3	-11,1	-20,6	-29,3	-43,5
Chemical, rubber, plastic products	0,5	-0,4	-1,6	5,2	5,1	3,7	-0,2	-18,5
Mineral products n.e.s.	0,0	0,0	1,4	-14,7	-20,7	-29,6	-44,4	-62,6
Iron and Steel	0,4	-0,2	0,8	-2,3	-8,1	-19,8	-36,7	-68,0
Non-ferrous metals	0,7	-0,7	-4,2	-0,7	-4,5	-7,5	-1,9	-1,8
Fabricated metal products	0,0	0,1	0,0	-3,9	-1,0	10,5	16,5	15,6
Motor vehicles and parts	0,0	0,1	-0,3	-3,4	-1,8	4,4	8,1	6,5
Transport equipment n.e.s.	-0,1	0,1	0,0	-4,4	-3,5	3,8	8,6	6,4
Electronic equipment	-0,1	0,1	2,2	0,5	2,7	9,2	11,5	12,0
Machinery and equipment n.e.s.	0,0	0,1	0,1	-3,2	-1,3	8,1	13,6	13,5
Manufactures n.e.s.	0,0	0,1	-1,7	-1,0	5,3	21,0	36,6	48,4
Electricity transmission and distribution	0,5	-1,6	72,4	165,5	161,5	157,1	154,9	160,7
Nuclear power								
Coal power	0,2	-0,2	-54,1	-98,4	-90,0	-88,3	-90,4	-90,1
Gas power	-0,1	-0,3	-5,2	-47,3	-62,7	-70,1	-73,7	-90,9
Wind power								
Hydro power								
Oil power	0,5	-1,6	72,4	165,5	161,5	157,2	154,9	160,7
Other power	0,5	-1,6	80,4	546,3	534,1	612,5	678,4	577,7
Solar power								
Water	-0,1	0,1	-0,1	-9,0	-9,1	-11,0	-11,6	-14,9
Construction	0,0	0,1	-0,4	0,9	-0,1	-1,4	-1,9	-0,8
Trade	0,0	0,0	-0,9	-10,4	-12,5	-14,7	-16,4	-19,8
Transport n.e.s.	0,0	0,0	-2,7	-9,2	-19,9	-31,0	-43,0	-53,5
Sea transport	0,0	0,0	1,0	0,6	2,1	-0,6	-1,0	-1,6
Air transport	0,0	0,0	0,3	-0,6	-3,9	-6,7	-11,5	-24,7
Market Services	0,0	0,0	0,0	-7,8	-7,9	-9,3	-11,1	-16,3
Non-market Services	0,0	0,0	0,0	-1,6	-1,6	-2,0	-2,1	-2,6
Dwellings	0,0	0,0	-1,0	-11,0	-13,4	-18,2	-20,9	-24,7
Households	0,0	0,0	-2,7	-9,3	-16,5	-30,9	-39,6	-44,6

Table 17. Employment, Decarbonization 1 scenario, by sector, 2015-2050, wage-bill weighted, in % change in wage-bill weighted employment from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,3	0,9	2,1	3,7	4,5	5,7
Livestock	0,0	0,0	0,3	-0,1	0,7	1,0	1,8	2,6
Coal	-0,3	1,4	-11,1	-12,1	0,3	-7,7	-18,7	-8,6
Oil	0,0	0,0	-1,6	-3,3	-11,5	-19,2	-29,7	-47,8
Gas extraction and distribution	-0,1	0,5	-2,0	-7,9	-42,0	-60,3	-80,3	-96,7
Other Mining	0,0	0,2	0,3	2,4	1,9	1,8	2,2	2,5
Food, Beverage and Tobacco	0,0	0,0	0,0	-0,8	-0,1	-0,9	-1,0	-0,4
Textiles and Clothing	0,0	-0,1	0,1	-0,4	0,8	4,1	6,0	7,0
Wood products	0,0	0,0	-0,1	-0,2	1,4	5,6	7,5	10,3
Paper products, publishing	-0,1	0,6	1,0	1,0	5,9	8,9	8,0	26,6
Petroleum, coal products	0,0	0,1	-2,2	-4,0	-12,4	-21,9	-31,9	-44,0
Chemical, rubber, plastic products	-0,1	0,4	0,0	4,0	1,6	0,4	-7,7	-19,5
Mineral products n.e.s.	0,0	0,0	0,2	1,1	2,8	4,5	6,2	10,0
Iron and Steel	-0,1	0,4	1,1	3,2	0,8	-4,1	-12,6	-27,7
Non-ferrous metals	-0,1	0,6	-1,0	7,4	8,3	15,7	36,3	62,4
Fabricated metal products	0,0	-0,1	-0,3	-0,8	0,3	5,5	7,4	6,7
Motor vehicles and parts	0,0	0,0	-0,4	-1,1	-1,0	0,7	1,4	0,7
Transport equipment n.e.s.	0,0	-0,1	-0,4	-1,5	-1,4	1,2	2,1	-0,1
Electronic equipment	0,0	-0,1	1,7	2,3	3,4	6,8	8,3	7,5
Machinery and equipment n.e.s.	0,0	-0,1	-0,2	-0,8	-0,2	3,6	5,9	6,0
Manufactures n.e.s.	0,0	0,0	-0,2	-0,9	-0,4	1,3	2,0	1,9
Electricity transmission and distribution	0,0	0,1	-1,9	-3,8	-6,3	-8,0	-9,7	-5,9
Nuclear power	0,0	0,1	-0,6	1,0	0,3	-2,7	-6,1	46,2
Coal power	0,0	0,0	-54,8	-74,7	767,5	17,6	-9,7	-5,9
Gas power	0,0	0,0	19,5	-2,6	-33,2	-47,8	-55,5	-92,3
Wind power	0,0	0,1	-1,9	1,0	0,3	55,9	183,7	337,6
Hydro power	0,0	0,1	-0,6	1,0	0,3	0,6	5,6	-13,2
Oil power	0,0	0,1	-1,9	-3,8	-6,3	-8,0	-9,7	-5,9
Other power	0,0	0,1	-10,5	32,0	16,5	170,4	190,9	172,8
Solar power	0,0	0,1	-0,6	1,0	163,8	145,2	139,0	119,5
Water	0,0	0,0	-0,1	-0,9	-1,0	-4,4	-5,7	-6,1
Construction	0,0	0,0	0,2	4,3	2,3	0,9	1,4	4,5
Trade	0,0	0,0	0,0	-0,4	-0,4	-2,4	-3,4	-3,7
Transport n.e.s.	0,0	0,0	0,2	-0,2	0,1	-5,9	-7,8	-7,5
Sea transport	0,0	0,0	0,7	1,5	2,6	-0,2	0,1	-0,5
Air transport	0,0	-0,1	0,1	-0,3	-2,7	-4,6	-6,9	-15,3
Market Services	0,0	0,0	-0,1	-0,7	-0,9	-2,7	-3,5	-4,0
Non-market Services	0,0	0,0	0,0	-0,1	0,0	-0,7	-0,8	-0,6
Dwellings	0,0	0,0	-0,2	-1,1	-1,5	-5,8	-7,5	-8,4

Table 18. Employment, Decarbonization 2 scenario, by sector, 2015-2050, wage-bill weighted, in % change in wage-bill weighted employment from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	1,0	4,6	6,5	7,2	7,9	8,4
Livestock	0,0	0,0	0,0	-0,6	0,1	0,9	1,7	2,8
Coal	1,0	0,6	-11,8	-14,0	5,7	-7,6	-19,7	-8,2
Oil	0,1	-0,1	0,1	-3,0	-10,6	-18,6	-29,1	-47,3
Gas extraction and distribution	0,5	0,3	-4,9	-12,5	-43,7	-60,6	-80,1	-96,5
Other Mining	0,2	0,1	-0,1	1,5	1,9	1,3	2,1	3,0
Food, Beverage and Tobacco	0,0	0,0	-0,3	-1,1	-0,9	-1,5	-1,5	-0,7
Textiles and Clothing	0,0	0,0	0,2	-0,1	0,6	4,2	6,1	7,0
Wood products	0,0	0,0	-0,4	-1,8	-0,5	4,2	6,0	8,8
Paper products, publishing	0,5	0,4	-1,8	2,6	12,3	16,2	16,8	36,7
Petroleum, coal products	0,1	-0,1	-0,3	-4,2	-11,6	-21,5	-31,5	-43,5
Chemical, rubber, plastic products	0,3	0,2	-0,9	2,2	3,4	0,2	-7,6	-18,1
Mineral products n.e.s.	0,0	0,0	0,1	1,0	2,9	4,4	6,0	9,7
Iron and Steel	0,3	0,2	0,5	1,5	0,2	-6,3	-12,4	-23,7
Non-ferrous metals	0,5	0,3	-1,4	6,1	10,7	15,7	37,0	64,7
Fabricated metal products	0,0	0,0	0,0	-0,4	0,2	5,7	7,6	6,6
Motor vehicles and parts	0,0	0,0	-0,3	-0,7	-0,9	1,0	1,7	0,9
Transport equipment n.e.s.	0,0	-0,1	0,0	-0,9	-1,6	1,3	2,3	-0,1
Electronic equipment	-0,1	0,0	2,1	2,9	3,6	7,3	8,8	7,9
Machinery and equipment n.e.s.	0,0	-0,1	0,1	-0,2	-0,2	3,9	6,2	6,1
Manufactures n.e.s.	0,0	0,0	-0,1	-0,7	-0,5	1,3	2,1	2,0
Electricity transmission and distribution	0,1	0,0	-1,5	-3,2	-4,3	-6,0	-7,7	-3,7
Nuclear power	0,1	0,1	-1,0	0,6	-0,3	-3,6	-6,7	47,4
Coal power	0,3	-0,1	-38,7	-92,9	-54,3	16,6	-7,7	-3,7
Gas power	-0,2	-0,1	3,6	-25,2	-50,3	-50,8	-56,0	-92,5
Wind power	0,1	0,0	315,3	86,3	-16,5	-19,1	-21,7	344,2
Hydro power	0,1	0,1	-0,6	1,1	2,5	-0,3	4,8	-12,4
Oil power	0,1	0,0	-1,5	-3,2	-4,3	-6,0	-7,7	-3,7
Other power	0,1	0,1	30,9	200,1	235,9	295,5	321,5	222,8
Solar power	0,1	0,1	-1,0	0,6	54,7	74,5	121,1	89,4
Water	0,0	0,0	-0,2	-0,8	-1,3	-4,5	-5,7	-5,8
Construction	0,0	0,0	-0,5	1,0	0,2	-1,3	-1,3	0,8
Trade	0,0	0,0	-0,1	-0,4	-0,6	-2,6	-3,5	-3,7
Transport n.e.s.	0,0	0,0	0,2	0,0	0,0	-5,9	-7,7	-7,2
Sea transport	0,0	0,0	0,9	1,4	2,3	-0,3	0,1	-0,3
Air transport	0,0	0,0	0,2	0,0	-2,7	-4,4	-6,8	-15,2
Market Services	0,0	0,0	-0,2	-0,6	-0,9	-2,7	-3,4	-3,7
Non-market Services	0,0	0,0	0,0	-0,1	-0,2	-0,9	-1,0	-0,8
Dwellings	0,0	0,0	-0,3	-1,3	-1,7	-6,0	-7,6	-8,0

Table 19. Employment, Decarbonization 3 scenario, by sector, 2015-2050, wage-bill weighted, in % change in wage-bill weighted employment from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,4	5,6	7,2	8,0	8,6	9,1
Livestock	0,0	0,0	0,3	-1,0	0,0	0,9	1,7	2,9
Coal	1,8	-2,3	-13,5	-13,1	9,6	-7,4	-22,3	-3,8
Oil	0,1	-0,1	0,2	-2,9	-10,4	-18,5	-29,2	-47,1
Gas extraction and distribution	0,9	-0,8	-4,2	-11,6	-42,4	-59,7	-79,7	-96,3
Other Mining	0,3	-0,4	-0,3	1,0	1,7	0,9	1,6	3,3
Food, Beverage and Tobacco	0,0	0,0	-0,1	-1,4	-1,1	-1,6	-1,6	-0,6
Textiles and Clothing	0,0	0,1	0,3	0,2	0,7	4,5	6,4	7,2
Wood products	0,0	0,0	-0,1	-1,9	-0,6	4,0	5,8	8,7
Paper products, publishing	0,9	-1,0	-2,5	0,0	12,4	16,0	17,9	41,1
Petroleum, coal products	0,2	-0,3	-0,2	-4,4	-11,5	-21,7	-31,8	-43,3
Chemical, rubber, plastic products	0,6	-0,7	-1,3	1,4	3,7	-0,5	-8,7	-17,8
Mineral products n.e.s.	0,1	-0,1	0,0	0,8	2,9	4,3	5,7	9,6
Iron and Steel	0,5	-0,5	0,2	0,5	-0,1	-7,6	-13,9	-21,3
Non-ferrous metals	0,9	-1,0	-1,9	4,6	10,7	14,9	35,6	65,0
Fabricated metal products	0,0	0,1	0,1	0,0	0,4	6,0	7,9	6,7
Motor vehicles and parts	0,0	0,0	-0,2	-0,5	-0,8	1,2	1,9	1,0
Transport equipment n.e.s.	-0,1	0,1	0,1	-0,5	-1,5	1,6	2,6	0,1
Electronic equipment	-0,1	0,1	2,2	3,2	3,6	7,6	9,2	8,0
Machinery and equipment n.e.s.	-0,1	0,1	0,2	0,1	0,0	4,2	6,6	6,3
Manufactures n.e.s.	0,0	0,0	-0,1	-0,5	-0,5	1,4	2,2	2,1
Electricity transmission and distribution	0,2	-0,3	-1,6	-2,1	-3,1	-4,7	-6,5	-1,9
Nuclear power	0,2	-0,3	-1,0	0,1	-0,7	-4,4	-7,8	46,2
Coal power	0,3	-0,1	-44,0	-92,9	-54,5	15,5	-6,5	-1,9
Gas power	0,1	-0,4	13,3	-31,5	-51,7	-51,1	-55,0	-88,8
Wind power	0,2	-0,3	291,4	74,6	-21,6	-24,5	-27,1	340,8
Hydro power	0,2	-0,3	-0,6	3,0	7,1	5,6	3,7	-13,2
Oil power	0,2	-0,3	-1,6	-2,1	-3,1	-4,7	-6,5	-1,9
Other power	0,2	-0,3	-1,4	261,8	267,9	332,2	359,7	235,1
Solar power	0,2	-0,3	-1,0	0,1	39,8	54,8	114,6	85,4
Water	0,0	0,1	-0,1	-1,0	-1,4	-4,6	-5,7	-5,7
Construction	0,0	0,1	-0,5	0,1	-0,5	-2,1	-2,3	-0,6
Trade	0,0	0,0	-0,1	-0,5	-0,7	-2,6	-3,5	-3,7
Transport n.e.s.	0,0	0,0	0,2	-0,1	-0,1	-6,0	-7,7	-7,1
Sea transport	0,0	0,0	0,9	1,4	2,2	-0,4	-0,1	-0,1
Air transport	0,0	0,1	0,3	0,2	-2,6	-4,3	-6,7	-15,1
Market Services	0,0	0,0	-0,1	-0,7	-1,0	-2,7	-3,3	-3,6
Non-market Services	0,0	0,0	0,0	-0,2	-0,3	-0,9	-1,0	-0,8
Dwellings	0,0	0,0	-0,2	-1,4	-1,8	-6,1	-7,5	-7,8

Table 20. Employment, Decarbonization 4 scenario, by sector, 2015-2050, wage-bill weighted, in % change in wage-bill weighted employment from reference scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Agriculture	0,0	0,0	0,4	2,6	3,8	4,6	5,3	5,9
Livestock	0,0	0,0	0,2	0,0	0,7	1,7	2,6	3,0
Coal	1,5	-1,4	-13,6	3,3	20,5	10,4	13,0	-9,1
Oil	0,1	-0,1	-0,5	-3,0	-10,3	-17,9	-27,5	-47,2
Gas extraction and distribution	0,7	-0,5	-4,7	-9,7	-41,9	-59,1	-78,4	-96,3
Other Mining	0,3	-0,3	-0,4	1,9	1,7	1,7	3,6	2,5
Food, Beverage and Tobacco	0,0	0,0	-0,1	-0,6	-0,2	-0,5	-0,4	-0,2
Textiles and Clothing	0,0	0,0	0,2	-0,8	0,2	4,1	5,7	7,0
Wood products	0,0	0,0	-0,2	-1,4	0,5	5,5	7,8	10,0
Paper products, publishing	0,7	-0,7	-2,8	8,1	16,4	23,0	30,9	38,9
Petroleum, coal products	0,1	-0,2	-1,1	-3,3	-11,1	-20,6	-29,3	-43,5
Chemical, rubber, plastic products	0,5	-0,4	-1,5	5,3	5,2	3,5	-0,5	-18,2
Mineral products n.e.s.	0,0	0,0	0,0	0,8	2,8	4,6	6,7	9,1
Iron and Steel	0,4	-0,3	0,0	4,2	1,5	-4,5	-7,2	-23,2
Non-ferrous metals	0,7	-0,6	-2,3	4,0	6,7	15,5	43,9	59,7
Fabricated metal products	0,0	0,1	0,0	-1,8	-0,7	4,8	6,6	6,9
Motor vehicles and parts	0,0	0,0	-0,2	-1,4	-1,3	0,6	0,9	0,7
Transport equipment n.e.s.	-0,1	0,1	0,0	-2,5	-2,8	0,2	0,7	-0,7
Electronic equipment	-0,1	0,1	2,2	1,2	2,5	6,1	7,1	7,6
Machinery and equipment n.e.s.	0,0	0,1	0,1	-1,3	-1,0	3,2	5,0	5,6
Manufactures n.e.s.	0,0	0,0	-0,1	-1,1	-0,8	1,2	1,9	2,0
Electricity transmission and distribution	0,2	-0,2	-1,7	-0,8	-2,3	-4,0	-4,8	-2,6
Nuclear power	0,2	-0,2	-1,1	0,7	-0,9	-4,1	-7,1	45,5
Coal power	0,4	-0,1	-40,2	-97,2	-0,9	15,9	-4,8	-2,6
Gas power	-0,1	-0,2	8,2	-47,8	-63,4	-67,5	-70,3	-89,0
Wind power	0,2	-0,2	386,2	1491,8	429,4	507,3	568,5	491,8
Hydro power	0,2	-0,2	-0,7	8,9	7,2	3,6	4,4	-13,6
Oil power	0,2	-0,2	-1,7	-0,8	-2,3	-3,9	-4,8	-2,6
Other power	0,2	-0,2	2,9	141,4	136,8	166,1	190,7	153,1
Solar power	0,2	-0,2	37,3	411,5	543,6	555,7	498,9	140,5
Water	0,0	0,0	-0,1	-0,9	-1,0	-3,9	-5,0	-5,2
Construction	0,0	0,1	-0,5	1,1	0,2	-1,3	-1,6	-0,7
Trade	0,0	0,0	-0,1	-0,5	-0,5	-2,2	-3,0	-3,5
Transport n.e.s.	0,0	0,0	0,2	-0,4	0,0	-6,0	-7,9	-7,0
Sea transport	0,0	0,0	0,9	0,8	2,0	-0,2	-0,4	-0,4
Air transport	0,0	0,0	0,3	-0,5	-3,0	-4,6	-7,2	-15,2
Market Services	0,0	0,0	-0,1	-0,9	-0,9	-2,4	-3,1	-3,4
Non-market Services	0,0	0,0	0,0	-0,1	-0,1	-0,8	-0,9	-0,8
Dwellings	0,0	0,0	-0,2	-1,3	-1,4	-5,3	-6,7	-7,5

FIGURES

TABLES

BOXES